Grinding Machines

SHAW

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GRINDING MACHINES AND THEIR USE

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THE MAIN PRINCIPLES, EQUIPMENT AND METHODS OF PRECISION GRINDING BASED ON LONG EXPERIENCE IN THE DESIGN, CONSTRUCTION, AND APPLICATION OF GRINDING MACHINES

FOR STUDENTS, MECHANICS, DESIGNERS, AND PRACTISING ENGINEERS

BY

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"PRECISION GRINDING MACHINES"; "MACHINE TOOLS"; ETC.

PITMAN'S TECHNICAL PRIMERS

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PREFACE

THE object of this book has been to embody in concise form the main principles of workshop precision grinding, and in the pages following will be found the results of many years' experience in the design and construction of grinding machines and close observation of their practical utility.

The subject matter is the basis of a series of lectures on grinding machines given by the author at the Royal Technical College, Salford. The author hopes, however, that the book will prove helpful, not only to the technical student, but also to the fully trained engineer, because precision grinding plays such an important part in all engineering work that every engineer should be aware of its possibilities. It is hoped the book will not merely be perused and put aside, but that it will be studied carefully and a desire thus be stimulated for closer acquaintance with actual grinding practice.

In the space available it has not been possible to give complete details of machines, and the reader who desires fuller information on these points is referred to *Grinding Machinery* by J. J. Guest, and *Precision Grinding Machines* by the author.

The author desires to place on record his indebtedness to the various firms who have kindly

assisted him with information regarding their machines, and by the loan of blocks ; also to the Norton Co., U.S.A., for permission to make extracts from their interesting trade publication, *Grits and Grinds.*

THOS. R. SHAW.

MANCHESTER.

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CHAPTER I

GRINDING WHEELS

THE forerunner of the modern grinding machine was the grindstone, which has been in use from time immemorial—and still finds useful applications. Between the modern grinding machine and the grindstone there is, however, nothing in common. The art of " precision " grinding has made great advances since the beginning of the twentieth century, largely owing to the demands of the automobile manufacturer, and precision grinding machines are capable of dealing with materials and obtaining a degree of accuracy quite beyond the powers of a grindstone. Mechanically, the grinding machine is a machine tool of the highest quality and there is an enormous difference between the grindstone—a solid block of soft natural stone—and the modern abrasive wheel which is made artificially from particles of extremely hard material. When the wheel is properly chosen and used these particles actually *cut* the work and do not " grind " or " abrade " it in the ordinary sense of these words.

Grinding is a Cutting Process. The operation of grinding, in which metal or other substance is removed by contact with a rapidly revolving grinding wheel, is an actual cutting process. The

cutting tools are hard, sharp particles of abrasive extending from the working face of the wheels. When these small, sharp tools—harder than any substance they are called upon to cut—are moved

Fig. 1.—Micro-Photograph of Chips from a Properly Operating Grinding Wheel.

at high speed into contact with the material to be ground, each particle cuts its own minute chip from the work. The modern grinding wheel, properly selected and used in the modern grinding machine, is just as surely a milling cutter as if it were made of steel. Under the microscope the

material removed is seen to resemble the chips from other machine tools, being, for instance, very similar to those produced by a milling cutter or lathe tool, see Fig. 1.

Abrasives.* These are of two kinds, natural and artificial. The *natural abrasives* emery and corundum are both mineral substances, similar in composition, except that emery is not as pure as corundum but contains a large percentage of iron, which is undesirable in a grinding wheel as it has no abrasive qualities.

Initially the principal abrasive available was emery, that most in repute, as being the purest, coming from Naxos. Deposits of nearly pure corundum have since been found, and this is the natural material now most in use.

The best grade of corundum is found in Canada, and has a higher percentage of aluminium oxide than has emery. Under the pressure of grinding the grains of corundum fracture, thus presenting new cutting edges or points to the work. Since both emery and corundum are natural products, they cannot be obtained free from all impurities.

Artificial abrasives have, to a very large extent, superseded natural abrasives in the manufacture of grinding wheels, because improvements in the design and construction of grinding machines created the demand for better and more reliable grinding wheels which could be used on them. The excellence of the grinding wheel as obtainable to-day is undoubtedly due to the requirements of the grinding machine.

* For further information on this subject see *Abrasives*, by A. B. Searle, uniform with this volume.

The artificial abrasives used are aluminous abrasives and carbide of silicon. Both of these are products of intense heat in an electric furnace. Aluminous abrasives are made from bauxite, a hydrate of alumina, which is found at Baux, France, and in several parts of the southern United States ; and silicon carbide is made from a mixture of coke, sand, salt and sawdust.

Abrasives Used for Various Materials. The extreme hardness and brittleness of carbide of silicon is an essential element in the successful grinding of metals of *low tensile strength,* such as cast iron, brass, bronze, and copper. It is also used for grinding granite, pearl, earthenware, firebrick, glazed sanitary ware, wood, cork, leather, and a variety of other articles. Wheels made from this abrasive by different makers bear various names including Crystolon, Carborundum, Carbolite, etc.

An abrasive material perfectly adapted to the grinding of materials of *high tensile strength,* such as steel and malleable iron, differs in essential characteristics from one suitable for the grinding of cast iron and brass. For materials of high tensile strength an abrasive must be hard and sharp and possess greater toughness than is required for the successful grinding of weaker materials.

Such extreme hardness and sharpness as is found in carbide of silicon is not essential or even desirable in an abrasive for the grinding of steel and malleable iron. The aluminous abrasives are therefore used for these metals, under trade names of Alundum, Aloxite, etc.

For the *grinding of steel,* then, an abrasive must possess the following properties: (1) A degree of

hardness which will permit it to penetrate easily into the material to be ground. (2) An irregular crystallization producing the property of sharpness. (3) A degree of toughness which will permit the crystals of the grain to stand up and not break down or fracture too rapidly under the strain placed upon them by the high resistance of a tough material during a grinding operation.

Such wheels cut rapidly and freely, but at such a rate and in such a way that excessive heat is not generated. They are used for all classes of steel grinding, varying from fine precision and tool-room work to snagging of heavy castings.

Bonding of Abrasive Wheels. The manufacture of abrasive wheels involves the processes by means of which the grains of abrasive material are bonded together into masses of specified sizes and shapes and desired degrees of coarseness and hardness. Three different processes are used: vitrified, silicate and elastic. Of these, the *vitrified process* is by far the most important, as it is possible to obtain a much greater range of grades or degrees of hardness in an abrasive wheel by this method than by any other. It is, therefore, possible to manufacture grinding wheels by the vitrified process that are adapted to a very great variety of grinding operations.

The bonding materials used in the vitrified process consist principally of fusible clays. The bonding clays are mixed with the abrasive grains in the proper proportions and the mass is formed or moulded into the desired size and shape. It is then thoroughly dried and placed in a vitrifying kiln. The kiln is brought to a temperature

sufficiently high to fuse or vitrify the bonding clays. When this vitrification is complete the kiln is cooled gradually and then opened and unloaded. The wheels are then finished or turned to exact size on specially designed lathes by means of rotary steel- or diamond-dressers. The arbor hole is sometimes bushed to the desired size and each wheel is tested carefully for balance and strength.

Silicate wheels, as the name indicates, are made by using a bonding material composed of silicate of soda. The proper amount of this material is mixed with the abrasive grain and tamped into an iron mould of approximately the shape and dimensions of the wheel wanted. It is then baked for about 20 hr. at a comparatively low temperature, high enough to cause the silicate bond to harden. The wheel is then ready for the truing room, and from this point onwards it is treated as a vitrified wheel.

With a few exceptions all wheels 30 in. in diameter and over are manufactured by this process. Wheels up to 60 in. in diameter are commonly made for cutlery grinding.

Silicate wheels are used where a wheel is required that has a somewhat softer grinding action than a wheel of the corresponding grain and grade manufactured by the vitrified process. They are used chiefly on dry tool grinding and similar work. There is also the advantage that wheels urgently required can be completed in three days by the silicate process.

In the *elastic process* the abrasive is mixed hot with shellac, run into trays, and allowed to cool. It is then broken up into its original size and the grains (each of which is now coated with shellac) are

put into hot moulds, rolled with hot rollers, allowed to cool, and then packed in quartz and baked in ovens at a temperature of 500° to 600° Fahrenheit. The subsequent treatment is the same as for vitrified and silicate wheels.

It is possible to make wheels by this process as thin as $\frac{1}{16}$ in., these being used chiefly for saw sharpening, grinding between the teeth of gears, sharpening moulding cutters and wood-working tools, cutting-off small stock, slotting and roll grinding.

Owing to the hardness of many high-speed steels it is impossible to cut-off small pieces of stock for lathe and planer tools in the usual way. The elastic wheels are very useful for this purpose and small cutting-off machines, fitted with such wheels, are made for tool room use.

Cutter Grinding. In order to keep cutters as well as other tools in properly sharpened condition in the easiest and quickest way, a cutter grinding machine should be used. This is generally a small machine having universal movements so that all kinds of cutters, reamers, etc., may be ground. Cup, saucer and dished grinding wheels in a variety of shapes and sizes are made for use in such machines.

Grain (or Grit) and Grade. The grain and grade of a wheel refer respectively to the size of grain and hardness. The grain or *grit* number indicates the number of meshes per lineal inch through which the grain has passed. The sizes of grain in use are numbered from 4 to 200 ; finer than 200 it is called flour, and designated by letters, F, FF, FFF.

The *grade* of a wheel is usually designated by letters, and means the degree of hardness of the wheel. An ideal grinding wheel is one that combines correct temper of abrasive grain (i.e. a grain that will fracture after the cutting point has

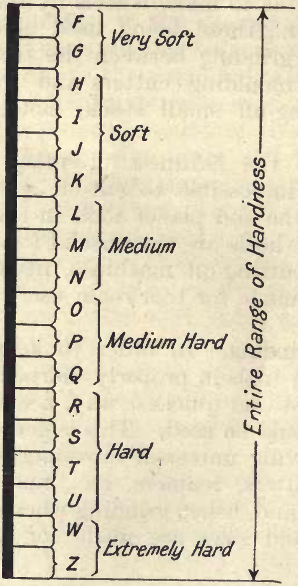


FIG. 2.—NORTON GRADE CHART

become dulled, thus presenting a new cutting point to the work) with a bond just sufficiently hard to hold the grain until it has performed its maximum amount of cutting, the grain then being released so as to present new cutting points to the work.

A grinding wheel is *too soft* when the bond

allows the grain to break away before it has become dulled, resulting in rapid wear, and *too hard* when the bond holds the grain after it has become dulled. In the latter condition the wheel becomes glazed, resulting in slow cutting and heating of the work.

A series of grades is just as essential as a series of grains to permit of the many varying combinations required in practice.

Wheels are graded from soft to hard, different methods of indicating grade being used by different grinding wheel manufacturers.

The Norton method employs the letters of the alphabet for vitrified and silicate wheels.

For elastic and rubber wheels, numbers are used to designate hardness. The Norton grade list is shown in diagram form in Fig. 2.

Elastic wheels are graded as follows—

SOFT — 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$; 3, 4, 5, 6 — HARD.

Selection of Grades. The factors that influence the selection of the grades are physical properties of the metal to be ground, shape and condition of the surface to be ground, speed of wheel, rigidity of the machine, and the method of grinding.

Soft wheels are used on hard materials like hardened steel. On softer materials, like mild steel and wrought iron, harder grades can be used.

The *area of surface* to be ground in contact with the wheel is of the utmost importance in determining the grade to be used. A strongly bonded wheel must be used if there is point-contact with the work, as when grinding a ball. If there is a broad contact, where the work brings a large part

of the wheel into operation, softer grades must be used.

Vibration in grinding machines necessitates the use of harder wheels. A softer grade of wheel can be used efficiently on rigid machines.

Reference to Fig. 3 will illustrate the practical influence of wheel contact upon the choice of a wheel. A wheel is shown in contact with four different varieties of work, all of which may be

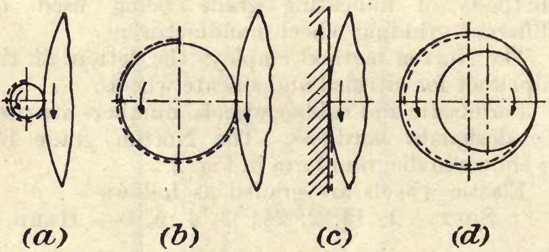


Fig. 3.—Illustrating Wheel Contact in Different Classes of Work

supposed to be of the same material, and the depth of cut, much exaggerated, being the same in each case. In case (*a*) the work ground is a shaft of small diameter and, the wheel contact being very small, a harder grade of wheel is required than in case (*b*) where a larger shaft is being ground and where the wheel contact is proportionately greater. To continue the comparison, diagram (*c*) shows the wheel grinding a flat surface, and at (*d*) the wheel is engaged in internal grinding. In these successive cases practice demands that the wheel shall be progressively softer in bond or grade, and this is

some proof of consistency in the action of grinding wheels.

As a wheel wears down the surface speed of the wheel is decreased (if the r.p.m. remain constant), and also, because of the smaller diameter of the wheel, which results in a smaller arc of contact between wheel and work, the grain depth of cut will be correspondingly increased. Similarly, it is true that as the work diameter is increased larger chips will be cut from the work and the thickness of these chips, or the grain depth of cut, must be lessened. These statements assume that, in analysing the effect of a particular factor, all other factors remain constant. Accordingly, a wheel should appear harder as the diameter of the work increases, or softer as it decreases; similarly, a wheel should appear softer as the wheel diameter decreases and harder as it increases.

Loading. If a wheel is forced into the work so deeply and so quickly that the material to be ground is crowded into the open spaces, filling them before the bond can be worn away by friction, the wheel is said to be loaded. With too deep and rapid feed loading will occur whatever may be the speed of the wheel, but it will occur most frequently when the speed is too slow. The clogged surface must be removed by dressing before the wheel can be used to cut as it should do. In this we have an analogy with the file and the milling cutter.

Glazing. A glazed wheel is one the cutting particles of which have become dull or worn down even with the bond, the bond being so hard that it does not wear away fast enough to leave spaces

between the cutting particles, and to permit the cutting particles to escape when dulled. A wheel of the right grade and grain may glaze if run too fast, and a wheel run at the right speed may glaze if it is too hard for the work.

One remedy for loading is to increase the speed. A remedy for glazing is to decrease the speed. If the speeds are right use a softer wheel in either case. Loading and glazing make necessary excessive dressing, and excessive dressing wears a wheel away faster than grinding.

The Effect of a Multiplicity of Cutting Points in Grinding.* "The lathe performs its work usually with a single pointed tool. The grinding machine employs a tool in the form of a grinding wheel which seldom has less than 50,000 points, and when using a larger and wider grinding wheel there are often from 500,000 to 800,000 cutting points. The volume of work that the lathe is capable of doing depends upon the strength and durability of the single pointed tool. The grinding wheel has a marked advantage over the lathe tool in this respect for the reason that, when the maximum strength and durability of a single point on the grinding wheel is reached, the wheel can be revolved at a greater or lesser speed in order to obtain the maximum strength and durability of all the other cutting points upon the face of the wheel.

"Grinding wheels are revolved for no reason other than to distribute the work among the entire number of cutting points. If it were physically possible to make the wheel with a grain so strong, so durable, that it would stand up under

* H. W. Dunbar in *Grits and Grinds.*

the cut for a long time, there would be no occasion for revolving the wheel. It could be used in just the same manner as a lathe tool. When we revolve the wheel at a sufficient speed to secure the maximum work each point is capable of performing without wearing away too rapidly, we then have the correct speed for that wheel.

"While the hard grades or strong wheels are performing a given amount of work in a given time at relatively slow speed, they do so with relatively greater pressure on the work. Soft wheels revolving at high speed can perform the same amount of work with less pressure, because with the greater speed each point is required to cut less each time that it comes in contact, and is enabled to perform the same work in a given time because it comes in contact more times during that period.

"For cylindrical grinding we therefore select the maximum revolution that is safe against breaking the softer grades of wheels, and use such of the softer grades as are suitable for certain material when these wheels are revolved at that number of revolutions per minute. When we need to use harder or stronger wheels for other materials or other forms of work, we select such grades as are suitable when revolved at the same revolution as the softer wheels."

Speed of Wheels. The surface speed at which to run grinding wheels remains practically constant regardless of the material being ground, and for cylindrical work varies from 5,500 to 7,000 ft. per min. The best average surface speed of grinding wheels made from artificial abrasives, is about 6,000 ft. per min. for external cylindrical grinding,

and the useful speed range is from 6,500 to 5,500 ft. per min. Below this speed excessive wheel wear is very probable, and grinding machines should be arranged so that the effective life of the wheel falls within this range. The effective life of the wheel is that portion outside the minimum diameter which can be used owing to the limitations of the machine, or the method of mounting. A variation of 500 ft. per min. makes no material difference, and it is best not to change the speed of the wheel in order to get a variation in results, but rather to change the speed of rotation of the work. It is of the utmost importance, however, that the speed of the wheel be maintained during the cutting operation, no matter what the speed may be, and the drive should be sufficiently powerful to prevent slowing down during momentary heavy cutting. Not only is wheel wasted by being allowed to slow down, but what is more important, the wheel face is destroyed and more frequent truing-up is necessary.

When the wheel has been worn down so that the peripheral speed falls below the satisfactory working speed, the speed of the wheel must be increased so that the proper speed can be maintained; otherwise, the farther the wheel wears the softer it will appear to become, although it is not actually so, this effect being produced by the reduced peripheral speed. When worn down below the speed range given on the machine the wheel should be transferred to a smaller machine and so utilized. (*See* table of Wheel Speeds, page 106.)

CHAPTER II

CYLINDRICAL GRINDING MACHINES

Use of the Grinding Machine. The cylindrical grinding machine has become fully recognized as a machine essential in every workshop for reducing the cost of cylindrical work. It was originated to assist the lathe in producing cylindrical work, and to make the process less expensive—not simply to replace filing. Those who would produce cylindrical work efficiently must recognize the fact that different cases require different degrees of refinement and, whether the work requires a low or a very high degree of refinement, the grinding machine is the only means for performing such work in an efficient and economical manner.

The lathe was originally the only machine for producing cylindrical work. The cylindrical grinding machine was introduced to perform the finishing operation and to give a more nearly perfect cylinder than could be produced by the lathe alone. The grinding machine produces precision work—not perfect work—but, when required, the accuracy can be made so much higher than when using the lathe, that the cylindrical grinding machine is rightly known as the precision machine, when compared with the lathe which it supplements.

The replacement of a steel tool by a grinding wheel was first adopted to deal with the problem of hardened work—the correction of distortion due to the process of hardening. In its early

days, the process—whilst giving higher accuracy and better finish than turning—was so tedious that it was confined to those cases where the requirements warranted the expense, such as the spindles of machine tools. Since that time the operation of grinding has obtained ever-increasing recognition. It was soon found to be indispensable for the production of interchangeable work, and did much to raise the standard of manufacturing accuracy, which, in turn, further emphasized the importance of the process.

It is well known to all engaged in the manufacture of precision machines and tools that the lathe is incapable of producing highly accurate work in an efficient manner, even in the softer metals, and in operating upon hardened surfaces it fails altogether. Grinding, therefore, means cheaper cost of all work, and cheaper turning than is possible without the use of the grinding machine.

The aim of every engineer is to obtain the best work in the shortest time and at the lowest cost. In the case of cylindrical work this ideal can be reached, whether it is necessary for the part to be exact to fine limits of error or not, by the combination of very rough turning with finish grinding. The real reason for removing metal is not to secure so many pounds of chips, but to accomplish certain finished results and, where the grinding wheel will enable this to be done more cheaply than the steel cutting tool, it is false economy not to allow it to do so.

Proper Relation of Turning to Grinding. The proper relation of turning and grinding operations, i.e. the amount of stock removed by the

lathe, the amount of stock removed in the grinding machine, the number and depth of the cuts, etc., can only be determined after scientific investigation of each piece to be finished. No rule can be laid down establishing this relation definitely and for all cases. Sometimes it is more profitable to grind direct from the black without turning at all; most times it is not.

Tradition tells the lathe operator that if he turns his work very close to size it will require less time for grinding. This is true, but it does not follow that the total cost of the two operations will then be a minimum. It may be, and often is true that by so turning the work that the grinding requires more time, the total cost is reduced, for it has been proved that *in any metal-removing operations which include finishing*, a point is reached when the grinding machine in some form or other will remove metal faster than other types of cutting tools.

Necessity for a Wide Range of Work Speeds. In cylindrical grinding work a given size of machine has to handle a great variety of different classes and different kinds of work, which naturally introduces as many different diameters of work. With a given grade of wheel, in order to keep the surface speed of the work constant so that this wheel will have practically the same cutting action on all these different diameters, it becomes necessary to introduce a speed-change device between the source of power which revolves the work and the work itself. This usually takes the form of gearing or belting, and a considerable range is provided to maintain constant surface speed on

all work, from the smallest to the largest sizes which can be ground by the machine.

The speed changes thus made possible, secure proper action of the wheel when grinding, and take care either of change in the diameter of the work, change in the diameter of the wheel, change in the composition of the material being ground, or change in the finish desired on the work.

It has often been claimed that it is impossible to obtain first-class results when grinding work which is driven by gears. Certainly it is, to say the least, very difficult to do this when using the ordinary form of tooth. Experiments were, therefore, made with various forms of teeth, and a form has been devised which gives the requisite sweet motion, and is so successful that it is easily possible to grind a mirror finish.

The Universal Grinder

The universal grinding machine is, as its name implies, capable of performing almost all grinding operations, including external work, parallel, or of any angle or taper; internal work; flat work held on a faceplate or in a chuck; and sharpening certain classes of cutters.

The life and usefulness of every machine tool depends largely on the care and skill of the operator, and this statement applies in an enhanced degree to the universal grinder. The highest standard of accuracy is expected in its product, and this can only be secured when the machine itself is accurate and in perfect working order. This calls for the utmost care in several directions.

The design must embody every possible advantage, so as to combine rigidity with ease of manipulation, the power to withstand undue wear, and such proportions as to distribute unavoidable wear so as to have the least possible effect on the quality of the work.

The workmanship must be of the highest class to secure the degree of accuracy in the various parts, without which the machine fails in the very object of its existence.

The materials of which the machine is built must be of the best quality, and the material for each individual part must be best suited to the duty which it has to perform.

Fig. 4 shows a view of a 12 in. × 36 in. machine made by the Churchill Machine Tool Co., Ltd., Manchester, complete with various attachments forming the standard equipment. The machine carries a grinding wheel 12 in. diameter by $1\frac{1}{2}$ in. face. Churchill grinders are built on the almost universal principle of a fixed wheel-head and moving table, i.e. the work being ground is carried past a grinding wheel running in fixed bearings. This method is generally acknowledged to be capable of producing the most accurate work with the least effort on the part of the operator.

The more rigidly the grinding wheel can be held, the less vibration there is on the machine, consequently better work can be expected, and the wear and tear on the machine are minimized. Thus with the construction illustrated in Fig. 4 the wheel head can be carried on a fixed part of the bed, and has the necessary rigidity for carrying large and heavy grinding wheels without vibration. As this part of the machine also carries the cross feed

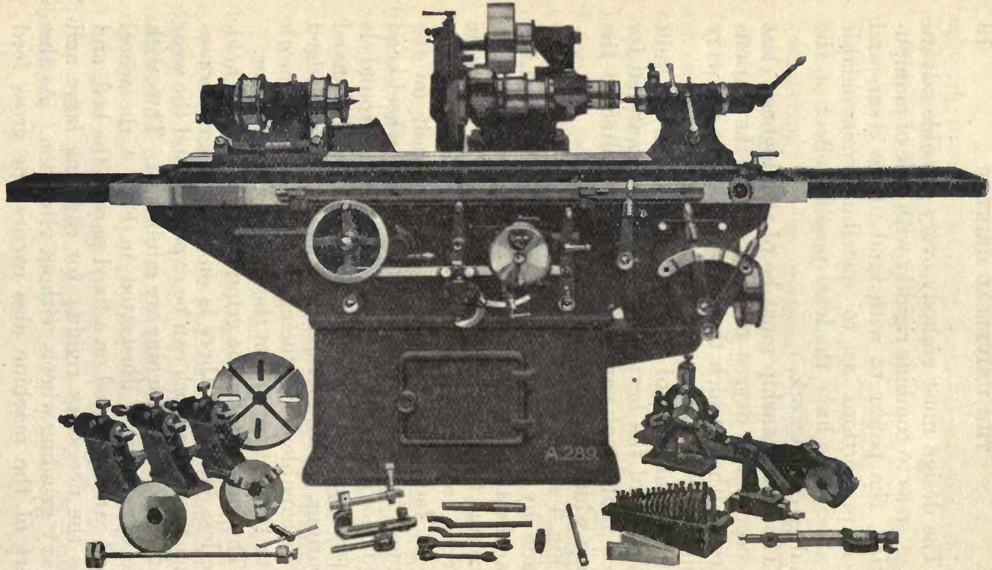


FIG. 4.—CHURCHILL UNIVERSAL GRINDING MACHINE
12 in. × 36 in.

mechanism, there is less liability to torsional deflection, thereby ensuring a sensitive control to the feed at all times. Further, in order to transmit the power necessary to revolve the grinding wheel to the best advantage, it is done through a single belt and pulley, and not through a long drum, as is necessary when the wheel travels.

The long table, long in proportion to the wheel slide, keeps the ways uniform and even as it travels to and fro over them (even if wear takes place), and preserves the alignment.

Another advantage in having the position of the cut stationary is that the operator can see it without moving from his position. With the moving wheel, there is the objection that the operator has to follow the grinding wheel up and down the bed. This on long work becomes a laborious operation, as the operator is bound to follow the wheel to adjust the work rests when opposite the cut.

A feature of the beds of these machines, and one generally adopted, is the *three-point bearing* upon which the bed rests. This makes the machine self-setting and independent of the irregularities of foundations. All operations of planing and scraping the ways are carried out with the bed resting on the three points, and so are the erecting and testing, hence, once the machine is built to work rightly the alignments are maintained.

Universal Head. For external grinding, the work is carried between the centres of the work-head and the tailstock, and is rotated by means of the dead centre pulley. The work revolves on dead centres—the only method of ensuring truly cylindrical work. Both the wheel-head and the

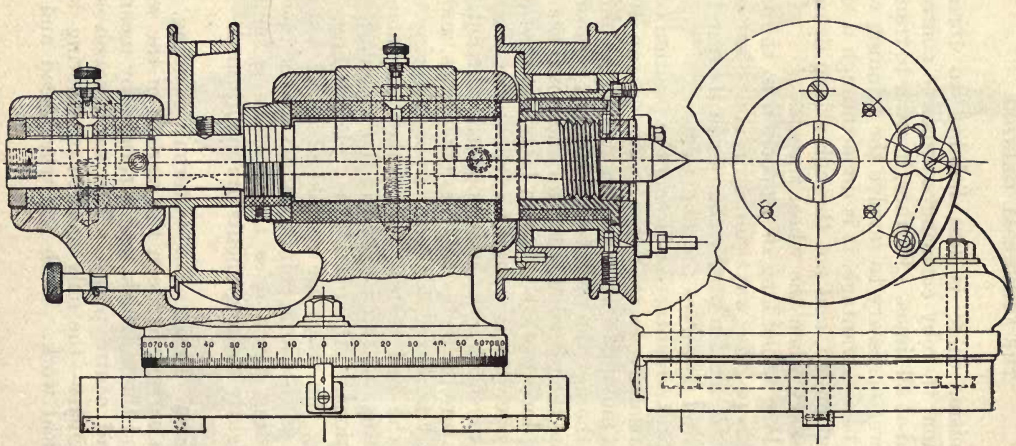


Fig. 5.—Brown & Sharpe Universal Work Head

work-head may be swivelled in a complete circle, allowing the grinding wheel to be presented to the work in any desired position.

For live spindle work, the dead centre pulley is removed. The spindle nose is threaded so that various attachments can be mounted. In the Churchill machines the spindle nose consists of two parallel surfaces of different diameters and one threaded portion. The threaded portion forms the driver, and the two parallel portions, being both accurately ground and perfectly cylindrical, ensure all fixtures which may be fitted being perfectly interchangeable and true running.

A sectional drawing of a Brown & Sharpe universal head is shown in Fig. 5.

When it is desired to grind work on dead centres, the spindle is held from revolving by a pin which enters the rim of the pulley keyed to the spindle. This lock is also useful when removing the dead centre pulley from the spindle nose, and putting on a face plate or chuck.

Tailstock. A view of the tailstock and one end of the table of a Churchill machine is shown in Fig. 6.

The tailstock spindle is provided with spring tension to allow for expansion of the work during grinding. The spindle is fully enclosed and operated by a conveniently placed lever at the rear. A suitable clamp provides for locking the spindle in position when necessary, but this should only be used when the work is heavy. The tailstock body is split and fitted with an adjusting screw for taking up wear. It is furnished with a convenient clamp with knurled thumb-screw for holding the

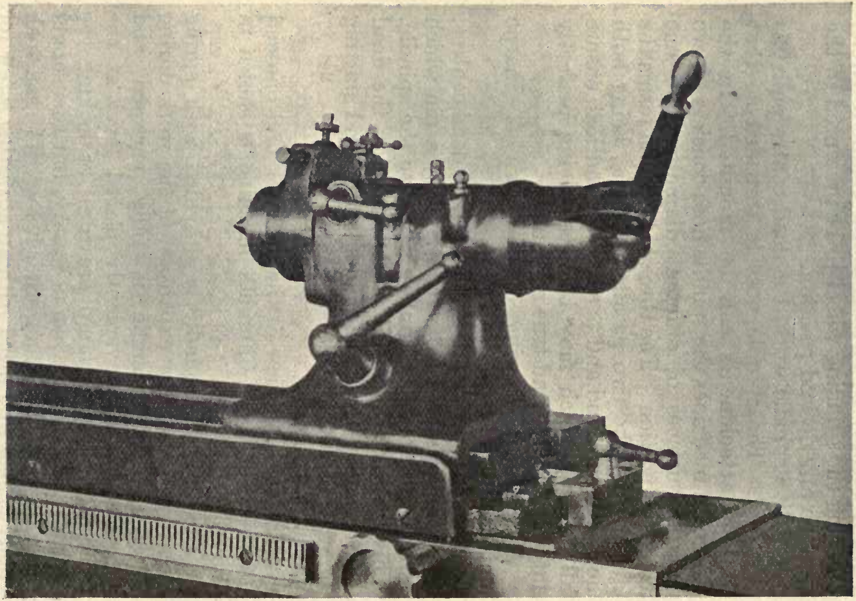


FIG. 6.—TAILSTOCK OF CHURCHILL UNIVERSAL GRINDING MACHINE

diamond tool when the grinding wheel is being trued, also a shield to protect the spindle from water and grit. The grinding wheel can thus be trued up without removing the work from the centres.

A special feature is the method of securing the head and tailstock in position on the table, (*see* also Fig. 29). Instead of being located by tongue pieces which fit in the central T-slot of the table—and which tend to wear loose and become unreliable—alignment is secured on these machines directly from the front edge of the upper table, which can be made and maintained true with the least possible trouble. The clamping is effected by bolts set diagonally, so that they pull the heads down and back into position, yet allow the utmost freedom of movement when released.

Table and Slides. The work table swivels on a hardened central stud and can be set at an angle to the ways for taper grinding. The adjustment is made by a screw at the end of the table, and a scale is fitted showing the angle in degrees and inches per foot. Locking devices secure the table in any position through its range of swivel adjustment.

The table travel is automatic and controlled by adjustable hardened steel dogs on front of table operating against the reversing lever. The dogs slide on a steel rack fixed on the table, and their position can be changed while the machine is running by simply pressing a thumb latch which engages with the rack. There is also a fine adjustment provided by means of a screw and thumb nut for use when grinding up to shoulders. The reversing lever has a spring plunger which can be

drawn back when desired, allowing the table to be run beyond the reversing points without disturbing the adjustment of the dogs. The spring plunger automatically assumes its normal position when the table is returned.

The base of the swivel slide which carries the wheel is graduated through half its circumference, and reads to 90 degrees either side of zero. When the slide is set at zero the line of motion is at right angles to the ways of the table, and when the slide is set at 90 degrees the two motions are parallel.

The satisfactory working of the machine depends to a large extent on the care given to the cross slide, which must be kept clean and well oiled. If allowed to get stiff and dirty the slide will lose that sensitive responsiveness which is so essential to accurate sizing. Remember that the slide is required to move exactly in accordance with the working of the feed pawl, that and it must advance by any desired amount down to 0·000125 in. ($\frac{1}{8000}$ in.), this being the movement produced by a single tooth of the feed ratchet. Such exactitude is only possible when the slide is in good order and working smoothly.

Obtaining Extra Fine Feed. When grinding gauges, or other work requiring a closer limit of accuracy than the finest feed of the machine, the following method will be found convenient. The bottom wheel slide is swivelled to an angle of 60 degrees from zero, the wheel head and top swivel being set in their normal positions as shown in Fig. 7.

Instead of traversing the wheel directly towards

the table, the feed motion now moves the wheel along a line at an angle of 30 degrees. As a result the actual feed is half that indicated by the graduations on the handwheel, and the finest feed

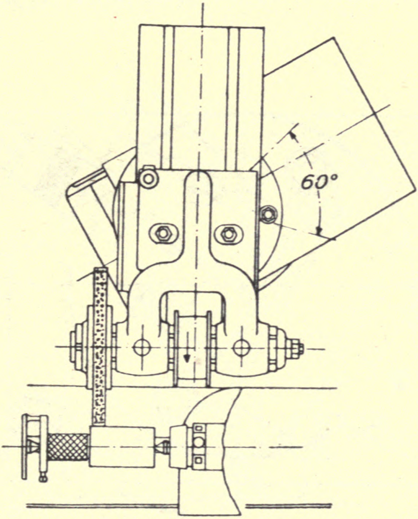


FIG. 7.—SETTING OF WHEEL SLIDE TO OBTAIN EXTRA FINE FEED FOR GAUGES, ETC.

is now $\frac{1}{16000}$ in. (0·0000625 in.), corresponding to $\frac{1}{8000}$ in. reduction in diameter, instead of $\frac{1}{8000}$ in. ($\frac{1}{4000}$ in. reduction in diameter). This plan will often be found of assistance in handling work where the greatest possible accuracy is required.

Taper Grinding, Etc. The adaptability of the universal grinding machine is further shown by

Figs. 8 to 10. Centres can readily be ground by setting the universal head to an angle of 30 degrees (*see* Fig. 8) and traversing the revolving centres past the wheel. If for any reason it were desired

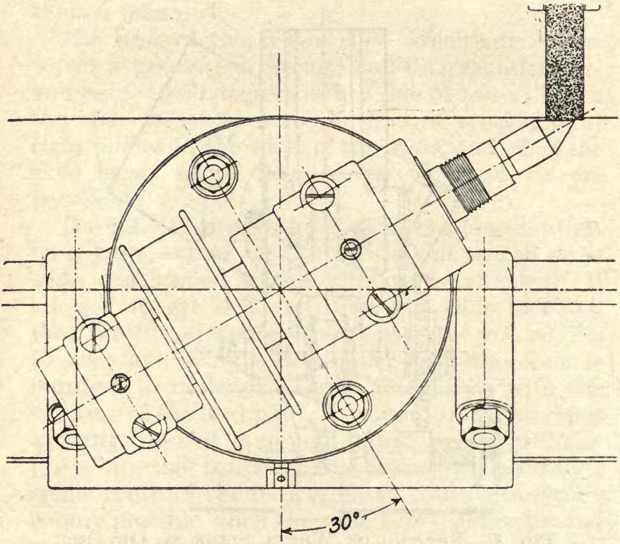


Fig. 8.—Truing Centres on Universal Grinder

to avoid disturbing the setting of the universal head, an alternative method of grinding the centres would be to swivel the wheel slide, and, with the wheel face parallel to the line of motion, traverse the wheel by means of the cross feed. In this case the table would, of course, remain stationary, being only moved by hand the slight amount necessary to put on the cut. Obviously this method involves

a good deal more trouble than that first described, and would therefore only be employed in exceptional cases. This method is also illustrated by Fig. 9, which shows the wheel head swivelled round to grind the bevel face of a piece carried on dead

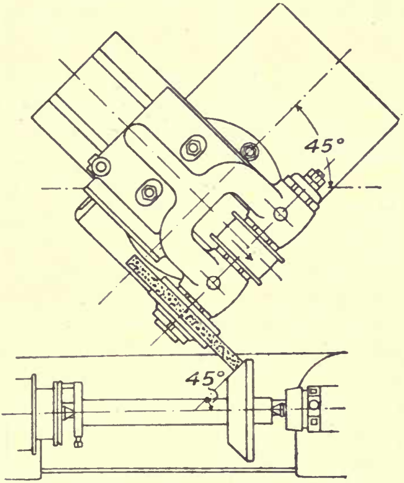


Fig. 9.—Grinding Angular Face with Wheel Slide Swivelled

centres. Fig. 10 illustrates the method of grinding taper work by setting over the top table.

Disc and Face Grinding. An *expanding chuck* usually forms part of the equipment and is found useful for disc grinding, such as thin milling cutters, saws, washers, etc. An example from Brown & Sharpe practice is shown in section

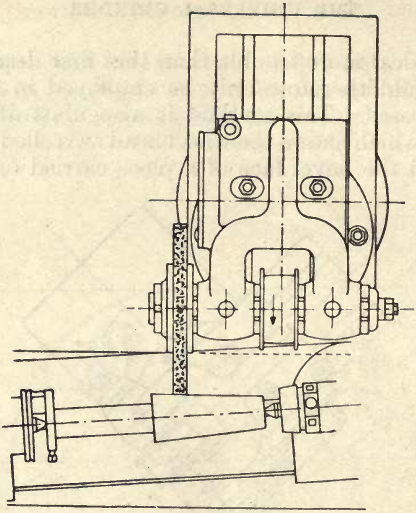


FIG. 10.—GRINDING TAPER BY ANGULAR ADJUSTMENT OF TABLE

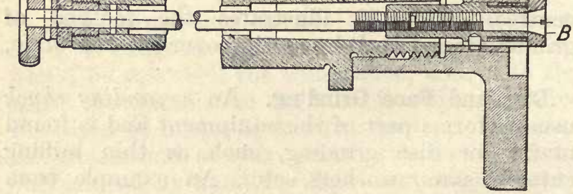


FIG. 11.—EXPANDING ARBOR FOR DISC GRINDING

Fig. 11. This chuck holds the work by means of a bushing expanded in the hole in the centre of the piece to be ground. The work is held by the bushing C, which is expanded by the screw B and drawn tightly against the face plate by turning the knob A. Different sizes of bushings are easily and quickly inserted to fit various sizes of holes in the work.

This face plate, together with the four-jaw chuck, when used in combination with the universal head of the grinding machine, is extremely useful in handling a wide range of flat and angular work, which would otherwise be impossible.

In *face grinding* the headstock is set round through 90 degrees ; the table for such work is, of course, set to traverse half the diameter of the work.

A note may here be given as to face grinding on the universal. As the area of contact between wheel and work is much greater in face grinding than in cylindrical grinding, more heat is generated, with a tendency to crack hardened thin pieces. Therefore a softer grade of wheel should be used than for cylindrical work of the same material, and there should be a plentiful supply of cooling lubricant. If a fine adjustment has to be made to obtain flatness of surface, it will be found much easier to effect it by means of the table screw than by disturbing the headstock setting.

Internal Grinding. The equipment of the universal grinder also includes provision for internal grinding. Fig. 12 shows the arrangement used on the Churchill machines. A range of spindles is made capable of dealing with various diameters

and lengths of holes. Each spindle is self-contained and immediate change can be made from one spindle to another, the supporting bracket A

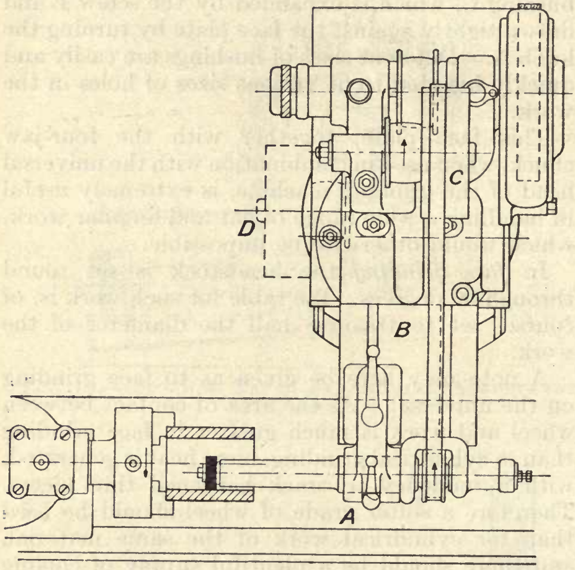


Fig. 12.—Internal Spindle Drive: Churchill Universal Grinder

A Supporting Bracket.
B Cross slide.
C Independent speed pulley.
D Position of pulley when external grinding.

on the end of the cross slide B being split and clamped for easy and rigid locking. The wheel head slide is, of course, swivelled round to bring the internal spindle into position. An independent

speed pulley C is used to drive the internal grinding spindle, and this is always in position on the top of the main wheel head. This construction avoids using the main spindle as a countershaft, and thus prolongs its life. It also avoids the necessity for removing the wheel and guard. Both external and internal spindles always remain in their working positions, the arrangement being such that the use of either does not interfere with the other. When the machine is used for external grinding the speed pulley C and its bracket are turned half-round to leave the drive clear to the main spindle.

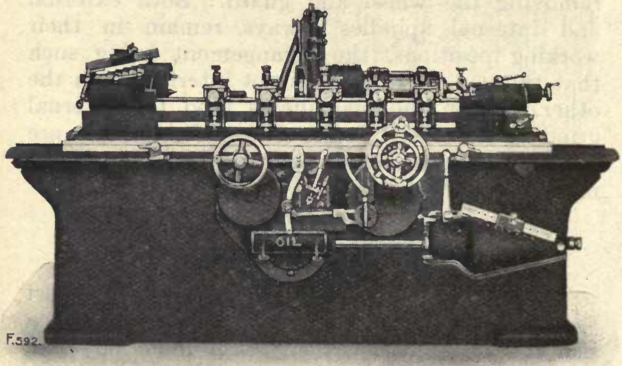
Plain Grinding Machines*

The universal grinding machine fulfilled most requirements for a time, but production on a manufacturing basis called for a more powerful machine of a more or less specialized character, and this machine, called the "plain" grinder, meets all requirements as to accuracy and finish, and enables all plain cylindrical work to be handled economically, which is not possible on the ordinary universal machine. Plain grinding machines are designed expressly for high production, and on account of their rigidity they are capable of turning out very accurate work. Frequently a grinder is used exclusively for the production of some particular machine part or duplicate pieces. Under such conditions it is possible to select a wheel graded in every way to

* For fuller information on this subject the reader is referred to the author's book *Precision Grinding Machines.* (Scott, Greenwood & Son.)

meet the grinding requirements of the particular work to be done. Machines are made having a capacity of 72 in. swing.

A representative type by the Norton Grinding Co., U.S.A., is shown in Fig. 13.



(Alf. Herbert, Ltd., Coventry)

FIG. 13.—NORTON PLAIN GRINDING MACHINE

Crankshaft Grinding. The finishing of crankshaft pins and bearings, both for single- and multiple-throw crankshafts, is a class of work peculiarly applicable to the grinding machine, owing to the high degree of accuracy and finish demanded. One of the difficulties encountered in any method of machining crankshafts is to secure alignment of the crankpins in relation to each other, owing to the gradual release of various stresses in the shaft forgings whilst the machining is proceeding step by step. It is for this reason that the grinding machine has been so successful

on this work, the removal of the surplus material by grinding being a more gradual operation, and one that does not impart further stresses to the shaft.

The method adopted in such grinding is to use a grinding wheel equal in width to the full width of a crank pin or bearing, no traverse being used. The fillets on the pins are formed directly by the wheel, the corners of the latter being rounded to the desired radius by a special truing device.

The crankshaft is carried in holders adjustable for any stroke, and provided with accurate index mechanism for four or six throws.

The procedure in crankshaft grinding is generally as follows—

1. Rough-grind journals.
2. Rough-grind pins.
3. Finish-grind pins.
4. Finish-grind journals.

The grinding of the journals should always be the final operation because it is important they should be in line. It must always be borne in mind that every operation of removing metal causes a change of alignment, and crankshafts are very susceptible to this.

Form Grinding. Form grinding consists in producing irregular or straight surfaces by the use of a wide grinding wheel, which is fed directly into the work without using the traverse. This method is used very frequently on some classes of work, especially for studs and other pieces of short length and, as already mentioned, the pins of a crankshaft.

Wheels up to 4 in. or 5 in. wide can be used

advantageously, but beyond this width there is difficulty in obtaining wheels of uniform grade throughout the full width, and there is also the greater difficulty in obtaining rigidity of work.

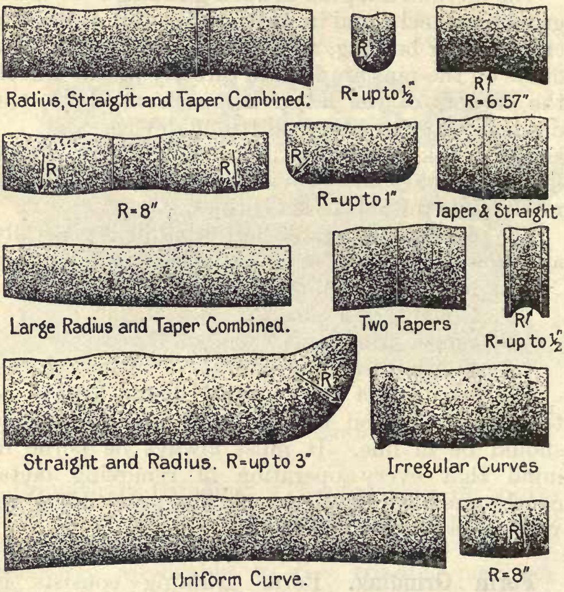


FIG. 14.—TYPICAL WHEEL FACES FOR FORM GRINDING

A typical instance of such work is the grinding of the taper shanks of twist drills, which is performed very successfully.

It is not necessary that the face of the grinding wheel always be straight. Various curved forms can be ground, and to make the wheel face to the

desired outline it is necessary to use a separate attachment fixed to the table of the grinding machine with a slide carrying a diamond tool. This slide is traversed against a former corresponding with the profile desired.

Some examples of wheel faces that have been used for form grinding are shown in Fig. 14.

Cam Grinding. The subject of cam grinding is interesting in view of the methods which have to be adopted to produce with fine limits of inaccuracy the particular contour or shape desired. In the case of the aeroplane engine camshaft, it is common to have 24 cams formed integrally on one shaft, and owing to the extremely high speed of rotation these cams must be finished with the greatest accuracy. Fig. 15 shows a cam grinding attachment for cams integral with the shaft.

There are two methods which may be employed in grinding a cam to its finished shape— (*a*) by oscillating or swinging either the work or the wheel, or (*b*) by a sliding action of either the work or the wheel.

The first method is the one generally adopted, and it gives the greater accuracy owing to its more sensitive control.

The shaft is carried on centres on an oscillating table. The oscillation at each revolution of the work is controlled positively by a hardened steel master cam in contact with a roller, and although a cam-shaft may have any number of cams, only one master cam is used, having two forms, one each for the inlet and exhaust. It is common practice to add a third form for the purpose of grinding the air pump eccentric. This does not

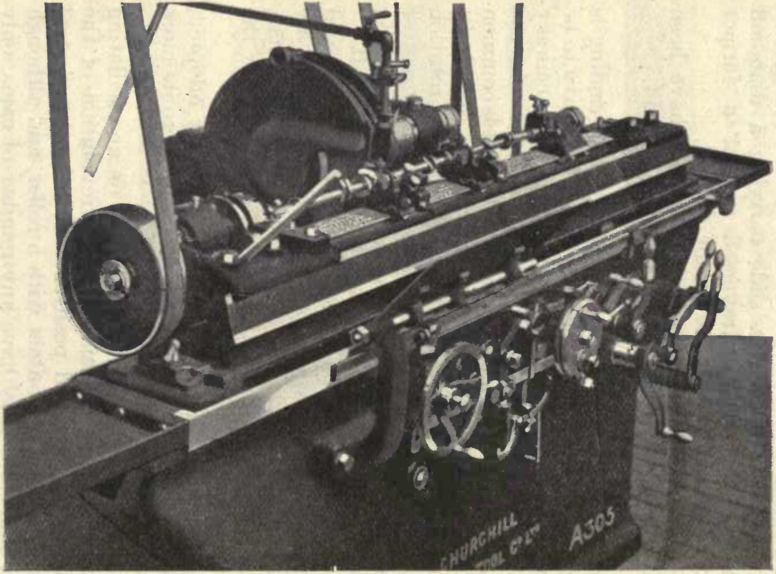


Fig. 15.—Cam Grinding Attachment on Churchill Plain Grinder

in any way affect the principle involved. The two or three forms, as the case may be, are always made from one piece of tool steel, generated, hardened, and ground to the correct shape, and with exact relationship between the inlet and exhaust, so that no variation can possibly occur in actual use. To take care of the varying number of engine cylinders and their respective cams a dividing plate forms part of the attachment. This plate is accurately divided corresponding to the number of cylinders used. This method of combined master cam is peculiar to the Churchill machines, and has proved particularly successful in meeting the exact requirements of the engine builders.

A further interesting adaptation of this method of grinding has been the finishing of the outsides of the webs of crankshafts for automobile and aircraft engines, thereby eliminating a large percentage of the tedious and expensive hand work otherwise entailed. All the faces are ground at one operation, and, apart from the large saving of time, the crankshaft produced by this method is in much better balance than one finished by hand methods.

Another example is the grinding of the external contour of turbine blades.

Roll Grinding. Chilled iron rolls are used to roll all kinds of sheet metal for the engineering trades, and they are used as calendar rolls in the textile trade, and as rolls for flour mills and allied trades. In almost every case a different type of finish is required, but in all cases the results demanded are very exacting, particularly where rolls with cambered surfaces are concerned. The grinding of a parallel roll is a comparatively simple matter once

certain conditions are compiled with, such as the correct mounting of the roll, the rigidity of the machine, and correct grade of grinding wheel, but the grinding of cambered surface rolls is much more difficult, particularly where rolls up to 30 in. diameter and 6 or 8 ft. long have to be ground with a diameter at the centre of the roll one or two thousandths greater than the diameters at the ends, the rest of the surface being spherical. It will readily be realized that very sensitive control mechanism is needed to regulate the movements of the wheel during the cambering operation.

It is essential that the roll be supported on its own necks, and a special design of roll support is used for this purpose. A truly cylindrical roll cannot be ground unless the roll necks are also cylindrical, and the design of the supports is such that the roll necks themselves can be ground to a true cylinder whilst rotating in the supports. Even if the roll necks are elliptical or oval to start with, they can be ground cylindrical whilst running in the supports. The fact that this can be done greatly simplifies the operation of roll grinding.

Centreless Grinding. The grinding of short pieces of work, such as studs and rollers, without the use of supporting centres is a method that has been adopted with varying degrees of success, and for work that comes within the range it is a very economical method of grinding. The machine is of very simple construction as there are no headstocks. In some machines the grinding wheel is tapered and in others a ring wheel is used having a plane surface, the work travelling in a path parallel to that plane, but, as in the case

of the tapered wheel, contact between the wheel and work is utilized for revolving and feeding the work.

The process of centreless grinding has also been applied to bars and rods, and such machines have generally been made by the users themselves, in particular, those specializing in the making of chains.

Internal Grinding Machines

There are two methods of internal grinding, the oldest and commonest being that in which the work is rotated and carried on a live spindle ; the Heald grinder shown in Fig. 16 is representative of this type. The other type is that in which the work is stationary and the grinding wheel spindle has a planetary motion. This method of grinding is suitable for work of an unbalanced nature, or for work that cannot conveniently be rotated.

Internal grinding is a commercial operation, and the factors governing production are much the same as in external grinding. The wheel diameter is limited by the size of hole to be ground and bears no direct proportion to it. For holes of less than 6 in. diameter the ratio of wheel diameter to hole diameter will be from 0·6 : 1 to 0·9 : 1. Provided that a suitably rigid spindle is employed, the grinding wheel diameter has very little effect on production, but it would be absurd to grind a 4 in. or 6 in. hole, using a 1 in. diameter wheel, because production would be limited by the weakness of the spindle that would have to be employed to carry such a small wheel. On holes of 9 in. diameter and upwards, the wheel diameter is affected not so much by the diameter of holes as by

the length, and also by the strength of spindle. There would be no gain in grinding, say, a 12 in. hole with an 8 in. diameter wheel if the spindle carrying the wheel were designed to carry only a 4 in. wheel. In such a case, production would be

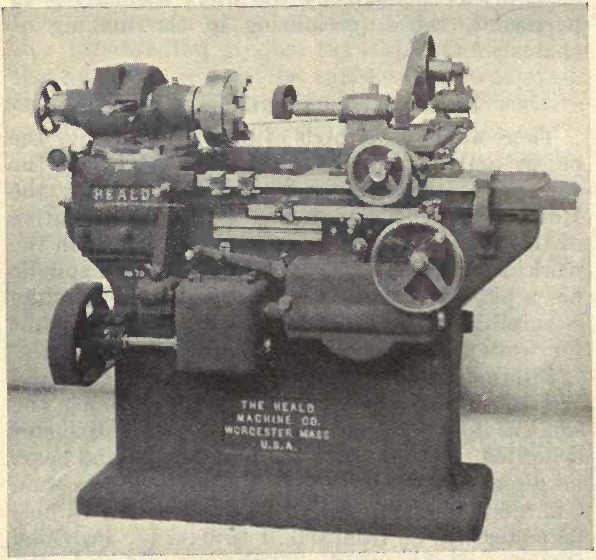


FIG. 16.—HEALD INTERNAL GRINDING MACHINE

governed by the rigidity of the spindle, other conditions being equal, such as wheel grade, surface speed, width, and traverse.

The grinding wheel surface speed for internal grinding has little effect on production, but such a statement requires a good deal of qualification.

Internal grinding has reached what might be termed an advanced stage in the works of the Churchill Co., and the results obtained have had a direct effect on the design of machines, and more particularly on the design of internal grinding spindles. It has been found that the effective speed range of a good grinding wheel is very much greater in internal grinding than in any other form of grinding, and ranges from about 1,000 ft. to 4,000 ft. per min. Much successful grinding is done at a surface speed of from 1,500 to 2,500 ft. per min., but such results have only been made possible by spindle construction embodying the utmost rigidity for the particular work in view. *Rigidity is, indeed, of more importance than actual wheel speed.*

Planetary Type Spindle Machine. For the second type of internal grinding there is a great diversity of work to be operated upon—including the grinding of holes in large castings, the bore of engine cylinders, liners, etc. For such service Messrs. Churchill have designed a machine in which the table carrying the work is stationary and does not traverse (*see* Fig. 17). With this arrangement there is no limitation to the external shape of work which may be dealt with. For instance, taking the ordinary knee type of horizontal milling machine, it is possible to grind the spindle hole, and also the hole for the overarm at one setting, ensuring absolute parallelism of the spindle with the overarm.

The grinding head of this machine is vertically adjustable on a column which reciprocates on the bed, the length of stroke being variable, depending

on the length of cylinder or hole to be ground. The grinding wheel spindle is driven at the high speed necessary for the grinding wheel, and has also an independent rotary motion, provided with varying throw, eccentrically adjustable whilst

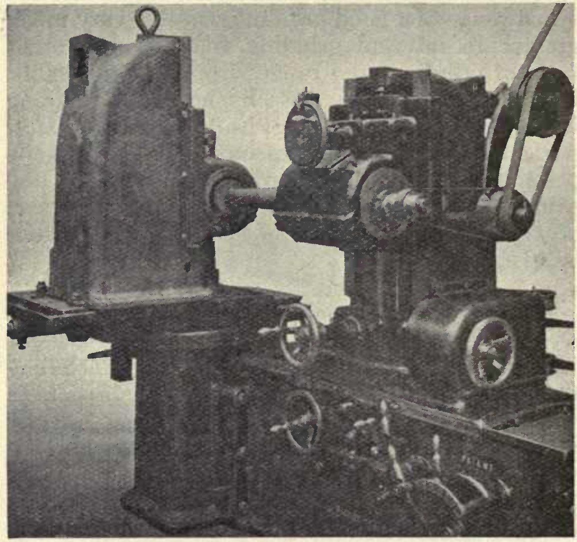


FIG. 17.—CHURCHILL CYLINDER GRINDER IN OPERATION

work is proceeding for the purpose of adjusting and feeding the wheel to the internal cylindrical surface of the work.

The grinding wheel spindle is self-contained and detachable from the main spindle, and may easily be removed and another size substituted. A full

range of spindles is made so that the smallest holes may be ground, and up to the maximum capacity of the machine.

Where this method of finishing holes is adopted, it becomes a vital factor in the design of machine parts, designs being modified so that they can be dealt with on this machine, resulting in accurate alignment of holes, interchangeable work, and corresponding cheapness of production. The machine might be termed of the "generative" class, inasmuch as on some classes of work it generates the alignment of relative parts automatically. The holes in many parts of machines can be finish-ground in correct alignment with previously finished locating surfaces or slides, correct alignment being thus secured with a minimum of correction by hand work.

CHAPTER III

PLANE SURFACE GRINDING MACHINES

THE production of plane surfaces by grinding is recognized as a cheap and efficient manufacturing process. On certain classes of work it will give a greater production than either milling or planing.

Types of Surface Grinding Machines. There are two methods of surface grinding—one using the periphery of the grinding wheel, and the other the edge or side of the wheel. The wheel in the latter case is of cup form and carried on either a vertical or horizontal spindle, the more widely used being the vertical spindle type. The two methods are further sub-divided according to the manner in which the work is moved, machines being made with the work carried on a reciprocating table, or on a circular revolving table. Four classes of machines may be classified briefly as follows—

(1) Horizontal-spindle surface grinding machine, in which the work is reciprocated under the grinding wheel.

(2) Horizontal-spindle ring and surface grinding machine. In this machine the work is carried on a circular revolving table, generally made in the form of a magnetic chuck, and is rotated under the grinding wheel. A machine of this class, made by the Heald Machine Co., U.S.A., is illustrated in Fig. 18.

(3) Vertical-spindle ring and surface grinding machine, in which the grinding wheel is of cup

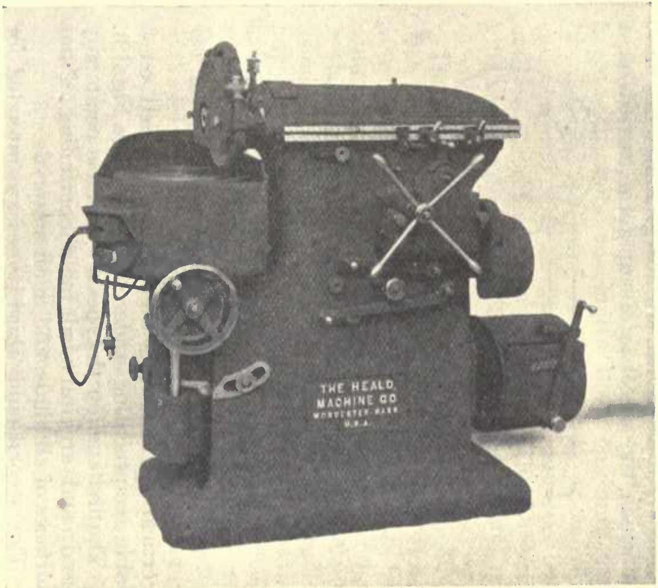


Fig. 18.—Heald Rotary Surface Grinder

form, carried on a vertical spindle, and the work is carried on a circular rotating table, generally in the form of a magnetic chuck, and is rotated under the wheel.

(4) Vertical-spindle surface grinding machine, in which the wheel is of cup form carried on a

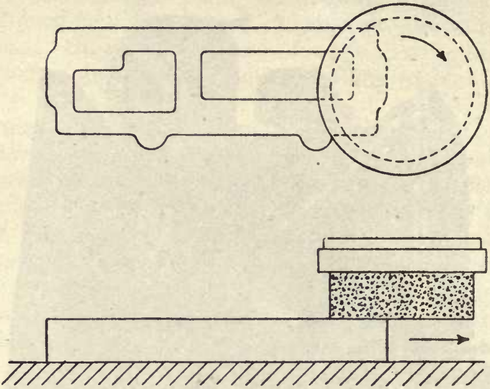


FIG. 19.—SURFACE GRINDING WITH CUP-WHEEL

vertical spindle, and the work is carried on a table reciprocating under the wheel (*see* Fig. 19).

The first and fourth types are the most commonly used, and are intended for the grinding of flat surfaces of all kinds, and in all materials.

The second and third types are intended for the grinding of the sides of disc work, such as circular knives and saws, piston rings, disc valves, etc., using the rotary table. The second type of machine, with horizontal spindle, leaves the work with a concentric finish, whereas the third type of machine, with the cup wheel, leaves the work with

a radial finish, which in some classes of work is objectionable, particularly, for instance, in piston rings, where the concentric finish is preferred.

So far as production is concerned the vertical-spindle machine will give a greater output than the horizontal-spindle machine. Both machines can be arranged to grind flat, concave, or convex surfaces, and it is impossible to recommend one machine in preference to the other without taking into account the work intended to be ground on the machine.

The vertical-spindle surface grinding machine with the cup wheel, which covers the full width of work at each stroke of the table, as Fig. 19, comes under Class (4), and has a distinct advantage in this respect over the horizontal-spindle machine using the periphery of the wheel, which would have to be traversed transversely in order to cover a work surface wider than the width of wheel. By the cup wheel work can be ground at one setting up to about 85 per cent. of the full diameter of the grinding wheel, and of a length governed only by the length of table travel.

Quite apart from the question of heat distribution, the vertical-spindle machine has the greater productive capacity, and for grinding wide surfaces or groups of small articles this type of machine has the advantage of the horizontal-spindle machine. The vertical-spindle surface grinding machine is adopted in all classes of engineering works, and wherever flat surfaces have to be produced, as in machine tool work, for instance, there is no method that can be compared with it for cheapness of production.

The Churchill Machine. This machine, Fig. 20, is designed on the unit system of construction—the body, upright, driving bracket, wheel head,

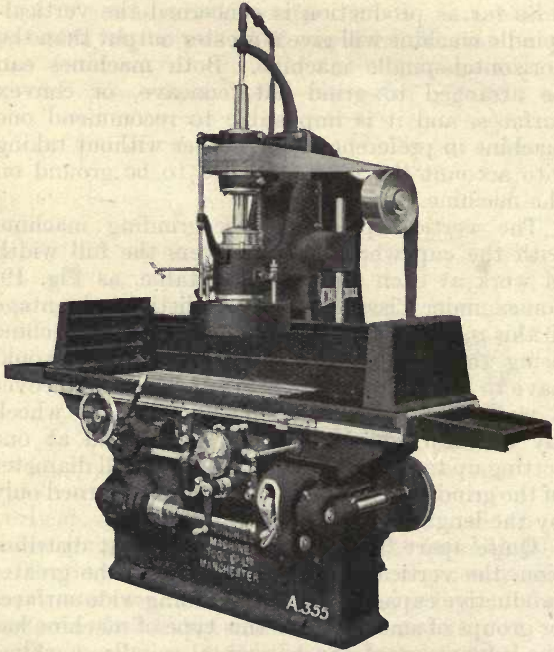


FIG. 20.—VERTICAL-SPINDLE SURFACE GRINDER

spindle-driving bracket, change speed gear box, and feed-control apron all being built as separate units to simplify construction and assembling of the parts. The spindle and all shafts and pulleys

run in ball journal bearings. Another special feature is the balancing of the spindle. This is arranged so that the spindle is pulled away from the work. This prevents any tendency to lost motion, and ensures perfect solidity of cut.

The wheel head is carried on square gibbed slides of great length on the upright, and has an automatic down-feed with trip motion, which ranges from 0·000125 in. at each stroke of the table. An important factor which cannot be ignored is the dissipation and distribution of the heat generated by the grinding wheel, and for this purpose the spindle is made hollow, and the coolant compound passing to the inside of the grinding wheel is thrown by centrifugal force between the wheel and the work, keeping them cool and washing them clear of grit.

Where this type of machine is used for grinding small articles in groups, the general practice is to cover the face of the table or the magnetic chuck as completely as possible, the object being to grind as many articles as possible at the one setting. This is not, however, always the most efficient method from a production point of view. Assuming the articles to be placed in one row, the full length of the table, then the time required per piece is the time required to grind one article. This production can approximately be doubled by adopting the method indicated in Fig. 21, which is to arrange two small groups, the centre of each group being spaced apart a length equal to the diameter of the grinding wheel. Instead of using one side of the wheel only, as is the case when a large number of articles is ground, both sides A, B, of the wheel are used, and the travel of the table is only that

necessary to cover one group. The illustration makes it clear that whilst the travel of the table is set for grinding one group only, two groups are

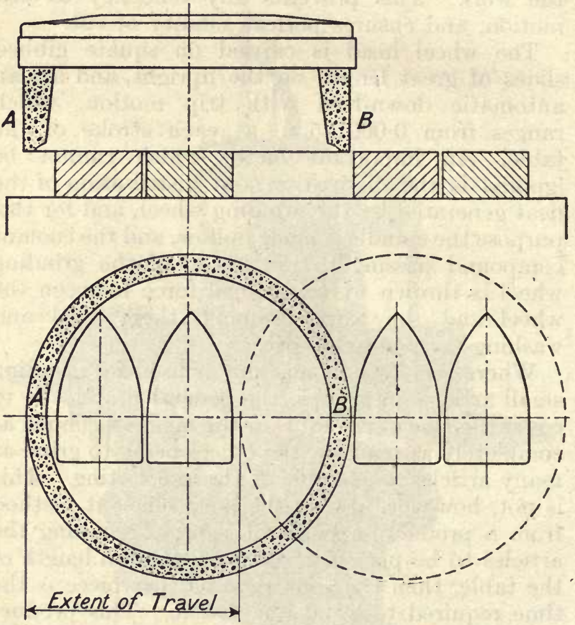


FIG. 21.—GRINDING SAD IRONS ON VERTICAL-SPINDLE SURFACE GRINDER

ground in the same time, both sides of the wheel being used at once. For example, in one case a Churchill machine ground four sad irons from the black to a fine finish in $1\frac{1}{4}$ minutes, removing approximately $\frac{1}{16}$ in. of metal. The dimensions

of the irons were 6 in. × 4 in., and the grinding wheel was 14 in. diameter.

Plano-Type Machines. To deal with large surfaces, vertical spindle surface grinding machines are also arranged on the planing machine principle, i.e. with a grinding wheel supported on a cross-slide, this in turn being carried on two uprights between which slides a reciprocating table. In this case the head has an automatic cross travel on the cross slide at each reversal of the table. Comparing the two types of machines, it would appear that for surfaces up to about 10 in. wide the standard vertical-spindle machine is the quicker producer, but on broader surfaces the plano-type machine is the quicker, as harder grinding wheels can be used with a smaller arc of contact and greater depth of cut as compared with the other type of machine, in which the limiting factor of production for cast iron surfaces is obtaining a soft wheel of exactly the right grade.

The Blanchard Machine. The machine illustrated by Fig. 22 comes under Class 3. (p. 46). It is made by the Blanchard Machine Co., U.S.A. The upright carrying the wheel head is a box casting resting on three adjustable points, this arrangement enabling the head to be set vertical and square with the chuck when grinding work of uniform thickness, or slightly inclined when grinding a convex or concave surface. The three supporting points are shown at *A*, Fig. 23. The spindle construction is shown later in Fig. 33. All work is held for grinding on the rotary table, which is 26 in. in diameter. This table is mounted on a

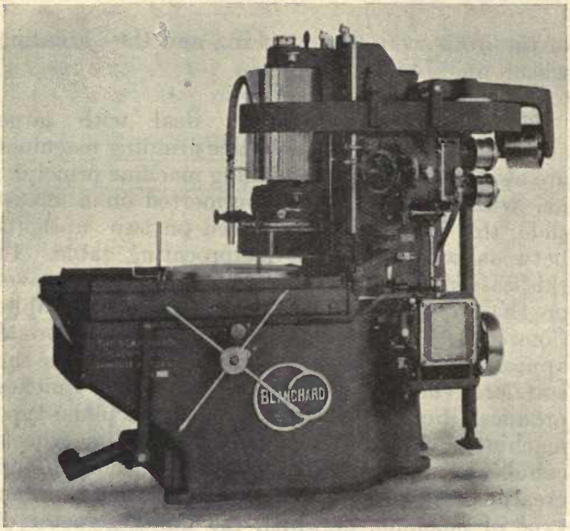


FIG. 22.—BLANCHARD GRINDER
Belt drive with 16 in. wheel

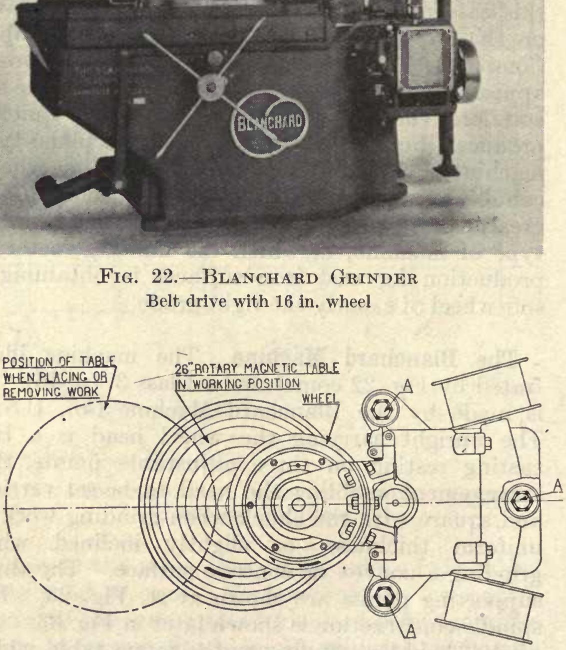


FIG. 23.—TABLE POSITIONS AND THREE-POINT COLUMN SUPPORT OF BLANCHARD GRINDER

sliding carriage so that it may be moved out clear of the wheel when placing or removing work. Only the rotary motion is used for grinding, and this is power-driven through a gear box giving a variety of speeds. The sliding carriage is operated by hand.

The rotary work table is a magnetic chuck with great gripping power. Tapped holes are provided in the face so that fixtures can be permanently screwed in place if desired. The chuck, therefore, combines the advantage of a plain and a magnetic work support.

The chuck is designed especially for the machine and is built by the Blanchard Machine Co. in its own shops. Its construction differs from other magnetic chucks in that the poles and body are all in one piece of forged steel. This elimates all joints from the outside and face of the chuck, thus making the chuck waterproof. The coils are former wound and are impregnated by the vacuum process. The completed chuck is a solid mass with no open spaces in its interior.

As will be seen by examination of the cross section of the chuck Fig. 24, the face is divided into narrow, concentric ring poles, so that even a small piece of work will touch two or more poles, no matter where placed on the face. Brass in the form of narrow strips is used to fill the grooves that separate the poles and is driven firmly in place. This chuck has only steel and brass in the working face and will keep a true surface and not charge with grit. The steel walls of the chuck body are all connected together at the bottom by a heavy plate of steel, both surfaces of the joint being ground flat to ensure good contact.

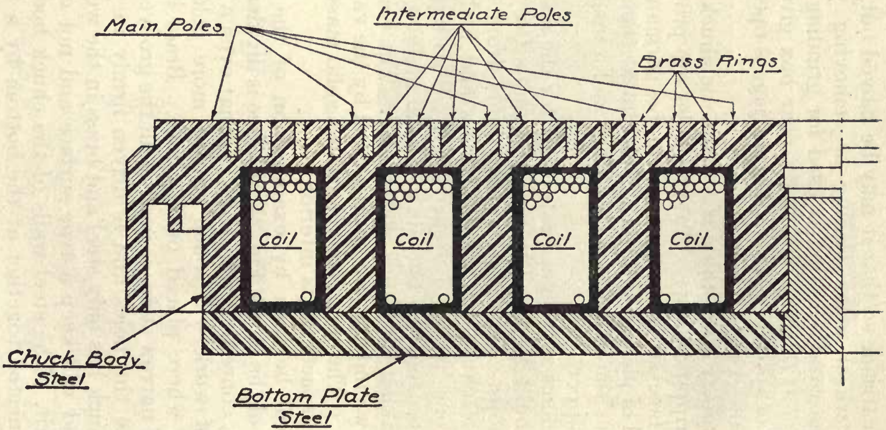


FIG. 24.—SECTION OF 26 IN. BLANCHARD ONE-PIECE STEEL MAGNETIC CHUCK

Each coil establishes a magnetic flux as shown by the arrows in Fig. 25 and, as the current in adjacent coils is opposite in direction, the magnetism in any one of the walls between coils, whether induced by the coil inside or outside that

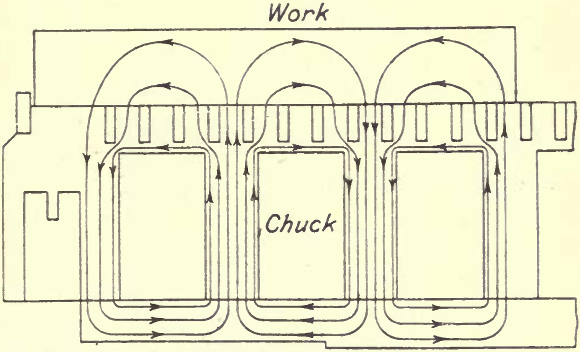


FIG. 25.—PATHS OF MAGNETISM IN BLANCHARD MAGNETIC CHUCK

wall, flows all in the same direction. If there were no brass rings or grooves in the face of the chuck the magnetism would find an ample path in the face of the chuck itself, and would not flow out of the face into the work and back again, as is necessary to secure magnetic holding of the work.

The arrangement of the electrical circuit is shown in Fig. 26, where *S* is the switch; *C* the cable; *B* the brushes; *R* the contact rings; and *T* the chuck terminals. Spring plungers *P* on the contact rings connect these rings to the terminals.

Continuous Reading Caliper Attachment. This attachment, supplied with the Blanchard machines,

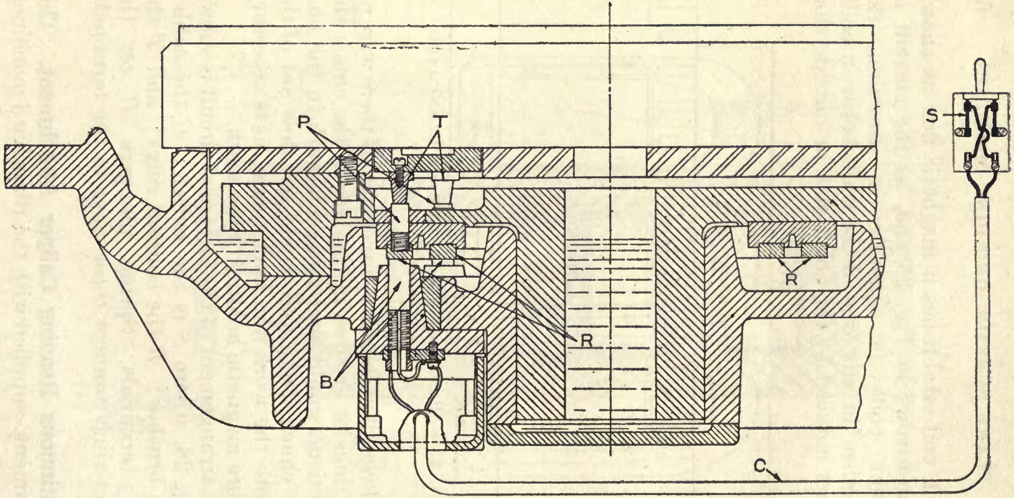


FIG. 26.—SECTION THROUGH TABLE OF BLANCHARD GRINDER, SHOWING ELECTRICAL PARTS

is a very convenient means for measuring the work and letting the operator know the exact size whilst the grinding is proceeding, thus eliminating the loss of time which occurs when work is

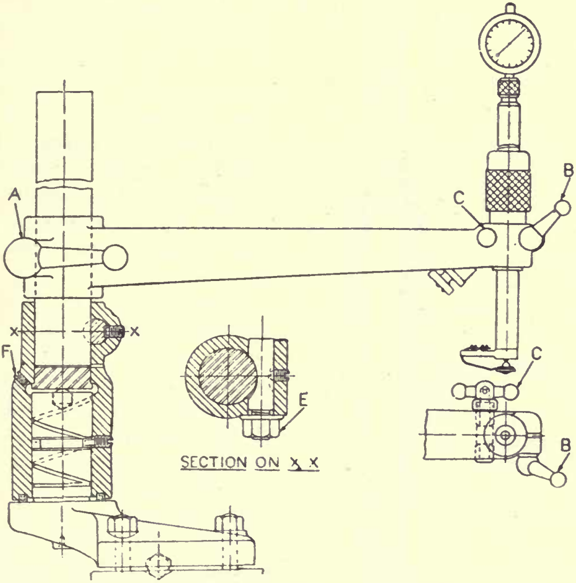


FIG. 27.—SUPPORTS FOR CONTINUOUS READING CALIPER. (BLANCHARD GRINDER)

stopped and the piece removed for measurement. The caliper operates by direct contact with the work and is entirely independent of wheel wear.

Fig. 27 shows the supporting arm, and Fig. 28 a section through the tube and its adjustments.

A hardened steel button rests lightly on the work and is connected to an "Ames" gauge-head which is placed at a convenient height for observation by the operator. The lower face of the button has the form of a very flat cone, and as its vertical movement is small it readily passes over openings in the surface of the work, or in the case of small work, from piece to piece.

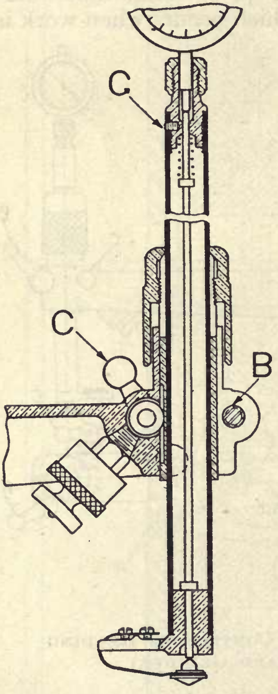


FIG. 28.—CONTINUOUS READING CALIPER (BLANCHARD GRINDER)

To set the caliper, the button is brought down on to a size block or finished piece placed on the table, and the dial of the gauge head is revolved to bring the zero line into agreement with the pointer.

In use, the caliper is swung on its pivot to bring the button on to the work while the latter is being ground. Each piece of work, as the motion of the table carries it under the button, indicates on the dial in thousandths of an inch, how much it is over size. The indication is easily read without stopping or

slowing the table motion, even when many small pieces are being ground.

The attachment is aligned to swing the button parallel to the table surface, so that correct readings can be taken at any convenient place on the work. The caliper swings out of the way for placing or removing work without disturbing its setting. It can be removed from the machine, when not needed, without disturbing its alignment parallel to the table, as the pivoted base need not be removed. The clamp bolt *E* is provided so that the pillar may be removed if desired.

The wear of the contact button introduces a slight error which, if uncorrected, would cause the work to be left more and more over size. By checking a piece now and then with micrometers and correcting the variation from size by slight adjustments of the button, this error is rendered entirely negligible. A fine adjustment of the tube carrying the contact button is made by handle *C*, clamping of the tube being effected by handle *B*.

With the exception of a few screws, all the parts over the work table, including the arm, are of bronze, avoiding errors that might otherwise be caused by the magnetic pull of the table. As the contact button rests on the work, it is not affected by magnetic pull, and to secure durability it is made of hardened tool steel.

Wheel Speed for Surface Grinding. The best wheel surface speed for all-round surface grinding is about 4,000 ft. per min ; but there is not the same margin of wheel speed for surface grinding as there is in external and internal cylindrical grinding ; that is, if a wheel is working successfully at

4,000 ft. per min., it cannot be varied up or down from this speed without affecting production. Consequently the vertical spindle machine, with the cup wheel has a great advantage in this respect, the cup wheel, retaining its diameter as it wears down, whereas, in the case of the horizontal spindle machine, the wheel diameter is reduced by wear and its cutting speed is reduced proportionately (unless the r.p.m. be altered).

Selection of Wheels for Surface Grinding. The grade of the wheel for surface grinding demands far closer attention and more accurate selection than is necessary in any other type of grinding. The only remedy for a wheel that is too hard or too soft is to change it for a wheel of the correct grade, and to adhere to this when once it has been determined.

In the surface grinding operation there is considerably more wheel buried in the work during the actual cutting time than there is with the same diameter wheel on a cylindrical piece of work. Hence for surface grinding it is usually safe to say that the wheels must be very much softer than for cylindrical grinding and that the wheels should be somewhat coarser to allow room for chips being removed whilst the particles of wheel are buried in the work. The same principle, of course, applies to cylindrical work; as the diameter of work gets larger and larger, the wheel is buried deeper in the part being ground than on smaller diameters, and therefore a somewhat softer and coarser wheel is required for the larger diameters.

The width of the surfaces presented to the wheel also has to be considered. Soft and coarse wheels are used for broad surfaces—hard and fine wheels for narrow surfaces.

Table I by the Blanchard Co. is a guide for the selection of wheels, and will enable a close approximation to be made. The table lists only wheels made by two firms, because the company's data are only reasonably complete for these two makes.

Mounting Wheels for Surface Grinding. Either fusible or Portland cement can be used to secure the wheel in the ring, no clamping devices being necessary. Fusible cement is amply strong and has the advantage that the wheels can be used at once. Portland cement requires 48 hours to set.

To use Fusible Cement. Clean the inside of the ring and the end of the wheel farthest from the wire bands. Set the ring on a level bench, place the wheel centrally in it, with the wire bands away from the ring, and pour in melted cement to fill the space between wheel and ring.

To use Portland Cement. Mix equal parts of Portland cement and sand with water to a thin paste. Wet the wheel thoroughly all over and spread a thin layer of the cement paste on the end farthest from the wire bands.

Clean all dirt and grease from the inner surfaces of the iron ring and place the wheel centrally in the ring, cemented end down. Then fill the space between the wheel and the ring with cement paste, using a thin piece of metal to ram it in place.

Remove all surplus cement from the outside of the ring and wheel and grease the ring. Then

TABLE I

Wheels for Blanchard Surface Grinder

Material.	Width of Surface.	Finer Finish and Narrower Surfaces.	Best Wheel for Average Work.	Faster Cutting and Broader Surfaces.	Finer Finish and Narrower Surfaces.	Best Wheel for Average Work.	Faster Cutting and Broader Surfaces.
		NORTON CRYSTOLON			AMERICAN CARBOLITE		
Cast Iron	Narrow	30–H	20–I	—	30–H	20–I	—
	Medium	30–G	20–H	14–H	—	20–H	14–I
	Broad	—	14–H	—	30–G	14–H	—
Chilled Iron	Narrow	—	20–I	—	—	20–I	—
	Medium	—	20–H	—	—	20–H	—
	Broad	—	14–H	—	30–G	14–H	—
Bronze	Narrow	—	20–I	14–I	—	20–I	14–I
	Medium	—	20–H	—	—	20–H	14–H
	Broad	—	14–H	—	30–G	14–H	—
Aluminium	Narrow	—	—	—	—	20–I	—
	Medium	—	—	—	—	20–H	—
	Broad	—	—	—	—	14–H	—
		NORTON SILICATE NO. 38 ALUNDUM			AMERICAN SILICATE CORUNDUM		
Malleable Iron	Narrow	—	3824-I	—	30–1	24–1½	—
	Medium	—	3824-H	—	30–1	24–1	—
	Broad	3830–G	3824-H	—	30–¾	24–1	—
Soft Steel	Narrow	3830-I	3824-I	—	30–1	24–1½	—
	Medium	3830-H	3824-H	3814-I	30–1	24–1	14–1½
	Broad	3824-H	3814-I	—	30–¾	24–1	—
Steel Castings	Narrow	—	3824-I	—	46–¾	24–1½	—
	Medium	—	3824-H	3814-I	—	24–1	—
	Broad	3830-G	—	—	—	24–1	—
Hardened Carbon Steel	Narrow	3846-H	3830-H	—	—	30–1	24–1
	Medium	—	3830-G	3824 H	—	30–¾	—
	Broad	—	3830-G	—	—	30–½	—
Hardened High speed Steel	Narrow	—	3830-H	—	—	30–1	—
	Medium	—	3830-G	—	—	30–¾	—
	Broad	—	3830-G	—	—	30–½	—

cover the wheel entirely with wet cloths and place it in a covered box or barrel.

Wheels should be allowed to set two days or more, varying with the brand of cement used.

If not already done by the maker, the inside of the wheel should be covered with paraffin wax painted on hot, to prevent annoyance from spray.

Safety. A grinding wheel should not be used on a vertical spindle unless protected against bursting stresses by means of a band of flat steel, or unless the wheel has been reinforced by the makers with bands of wire. The wheel should be mounted with these bands away from the retaining ring. When the wheel is worn down to within $\frac{1}{8}$ in. of a band, the band should either be cut off or pushed up against the band above. Unless the wheel is badly cracked, cut the band off and do the same with the second band when it is within $\frac{1}{8}$ in. of the face of the wheel. If the wheel has several cracks, extending part or all the way from face to ring, it is advisable to push the bands up and not remove them until there is no longer room for them on the wheel.

Lubricant for Surface Grinding. A good cutting lubricant for general work is—

Water . . .	. 50 gallons.
Soda . . .	. 5 to 7 pounds.
Machine oil . .	. 1 to 2 quarts.

The oil improves the finish of the work and helps to prevent rusting, and to prevent the work drying white.

The use of grinding compounds as used in cylindrical grinding machines is not recommended. Troubles frequently met with in using compounds are—(1) Foaming so as to overflow the tank; (2) the chips, being slightly magnetized, have a tendency to become a solid mass, clogging the feed pipe. The soda in the recipe shown on page 65 dissolves this mass and leaves the pipe clear.

CHAPTER IV

CONSTRUCTIONAL DETAILS OF GRINDING MACHINES

Importance of Rigidity. There is probably no machine tool in use the value of which is more dependent on rigidity than is that of the grinder Also this is one of the essentials that is not always apparent at the outset, but to the practical man it is of particular importance. The tendency of working parts to vibrate, thus impairing the accuracy and finish of the work, is resisted by the rigidity of the machine, which ensures alignments being maintained. Without rigidity a successful machine is impossible.

Present-day manufacturing demands both quality and quantity, and the more rapidly a machine is operated the more prone are its parts to vibrate, so that rigidity becomes vital to successful production. Running at high speed, revolving work, and abrupt reversal of table at ends of traverse, all conduce to vibration, and so, too, do the forces on the wheel when cutting. Vibrations of the work during operation cannot always be attributed to lack of rigidity in the machine. There are numerous minor causes that give rise to vibration, but it is generally easy to locate and remedy such sources of trouble. Where, however, a machine is incapable of taking cuts at speeds and feeds consistent with modern good practice, the fault usually lies in either the design or the construction of the machine, or in both.

Another factor contributing to the success of a grinder is the alignment of the various parts and mechanisms. Any error in alignment is invariably communicated to, and very often multiplied in, the work, and where this is of a fine character the slightest errors are sufficient to impair its quality. As the chief value of the grinder lies in its ability to produce work within very close limits of inaccuracy, alignments assume a paramount importance, and if they are not dependable then the utility of the machine is restricted.

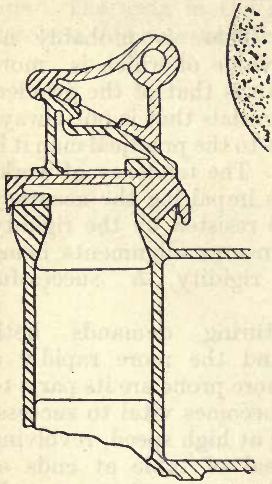


FIG. 29.—CROSS-SECTION OF PLAIN GRINDER

Plain grinding machines are subjected to a much heavier class of work than is the universal grinder; hence the design of the work head, tailstock, and supporting steadies differs in the two styles of machines. Fig. 29 shows an example of the construction of these parts in a plain grinder. It will be seen that the work centres are located directly above a solid wall of metal, which extends to the floor; and the outward thrust of the wheel against the work is brought to bear upon the front wall of the base.

A grinding machine table is guided and supported

by one V and one flat way. The long guide resulting therefrom ensures an accurate and straight line movement, but it is essential that the guiding surface be made a true straight line in the first instance. The top table of a plain grinder is of a special form most suitable for keeping water from the front mechanism, and also for providing a face which can easily be made straight. On this face depends the truth of the machine, for when the heads are moved from one position to another to accommodate different jobs, it is essential that they maintain a straight line and that the work head and tailstock centres exactly coincide. The clamping bolts are so arranged as to pull the heads on to the aligning faces, as in the universal grinders already described. The strong ribbing of the sliding table is shown clearly in the view of the under side (Fig. 30). This construction entirely overcomes the tendency of the table to sag when at the end of the traverse.

The Wheel Head. The construction of the wheel head calls for very special care, both in design and workmanship. Any lack of rigidity in this portion of a grinding machine makes it unable to meet the demands of work both as to quality and quantity.

The wheel head must be heavy enough to carry the largest and the broadest wheel with which the machine may possibly be fitted, and also to overcome any possible want of balance in the wheel itself. For the same reasons the spindle and its bearings should be of ample proportions to withstand the above forces without requiring frequent adjustments. It should be emphasized that the

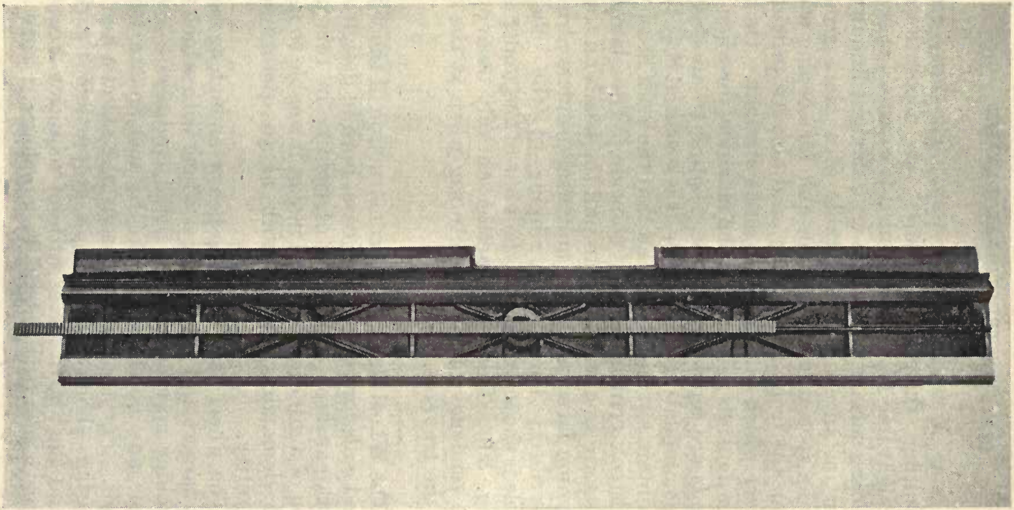


Fig. 30.—Under-side of Sliding Table

work produced on a grinding machine is only a reproduction of the grinding wheel itself. For cylindrical work the grinding wheel must be a perfect cylinder, otherwise good work cannot be produced, and, unless a grinding wheel head has the rigidity necessary to overcome possible adverse conditions in the wheel itself, it is impossible to make a wheel perfectly cylindrical, and failure is the result. It is for this reason that a grinding machine cannot very well be improvised. Many attempts have been made to convert the lathe into a grinding machine by means of attachments, but such attempts can only meet with very moderate results owing to the lack of the necessary rigidity.

The grinding wheel spindle and its bearings are examples of the highest class of workmanship, and there is no other detail on any machine tool from which such exacting duties are required. Efficient lubrication is the first consideration. The high speed, combined with large diameters and the necessarily close running fit, make the lubrication of vital importance.

Before being sent out by the makers, the spindle of a grinding machine is usually tested and tuned up to correct running fit. The adjustments should not be tampered with, and any adjustment required to take up wear should be undertaken by some responsible person with a knowledge of the construction of the bearing, and the conditions under which the spindle should run. Spindles are known to have run for two years without requiring adjustment.

To be in good running condition the bearing should be at a temperature of 100°-120° F. To

maintain the temperature constant a grinding wheel is usually left running all day long, even when all other motions are stopped.

Unless proper attention is given to the lubrication, the best spindle will quickly be ruined. A film of oil should be maintained, so that there is never metal to metal contact between the spindle and bearing. A medium heavy-bodied oil should be used, of such viscosity that it will not run away at 100°-120° F. The oil should be perfectly clean, and the oil-well should be drained occasionally.

Wheel Spindle Construction. In order to maintain the close fit necessary on the spindle bearings, they are designed taper on the outside so as to be easily adjusted by movement parallel to the spindle axis. This adjustment has the advantage of giving perfect control with long life and preserves as nearly as possible the original alignment, which is of the utmost importance with the wide grinding wheels now in use.

Where split taper bushes are used, they have a tendency to close in on the spindle at the plane of severance, independent of the action of drawing-in by means of the adjusting nuts. This is an objectionable feature in the spindle of a grinding machine, as it is essential to the true and steady running of the wheel that a uniform fit be maintained all over the surface of the bearing.

To counteract this tendency the top part of the bush is usually provided with a dove-tailed slot into which are fitted two steel pads. These are held in position by cheese head screws, which are drawn up tight after the bearing has been

finally adjusted. The action of the inclined faces of the pads causes the split bush to be forced apart at this point and prevents any tendency to close too tightly on the spindle.

When wear takes place these pads are slackened by unscrewing the screws which hold them (they are not taken out), and after the bush has been closed-in by drawing it into the taper, the pads are again drawn tightly into place.

The construction of the wheel spindle of the Churchill universal grinder is shown in Fig. 31. Here the bearings are of a patented construction, and while taper on the outside and split (into three distinct pieces) so that they may be compressed when wear takes place, they are of solid construction, no grooves being left in the bearings from which oil may escape. It is thus ensured that the bearing shall have a long life. The three parts of the bearings are held together by a band of special metal, which also fills the spaces that would be left by the grooves in the ordinary construction. This special metal is compressible and allows the bearing to be closed in as desired, giving a uniform fit over the whole surface of the bearing.

A peculiarity of all Churchill spindles is a number of fine spiral grooves, which are cut in the spindles at each end of the bearing to assist in preventing the leakage of oil. These tend to force the oil back again into the oil chamber, and so help to maintain a constant circulation.

The wheel spindle itself is of chrome-nickel steel, and undergoes a special heat treatment which makes the texture of the spindle close and ensures an efficient running surface. This heat

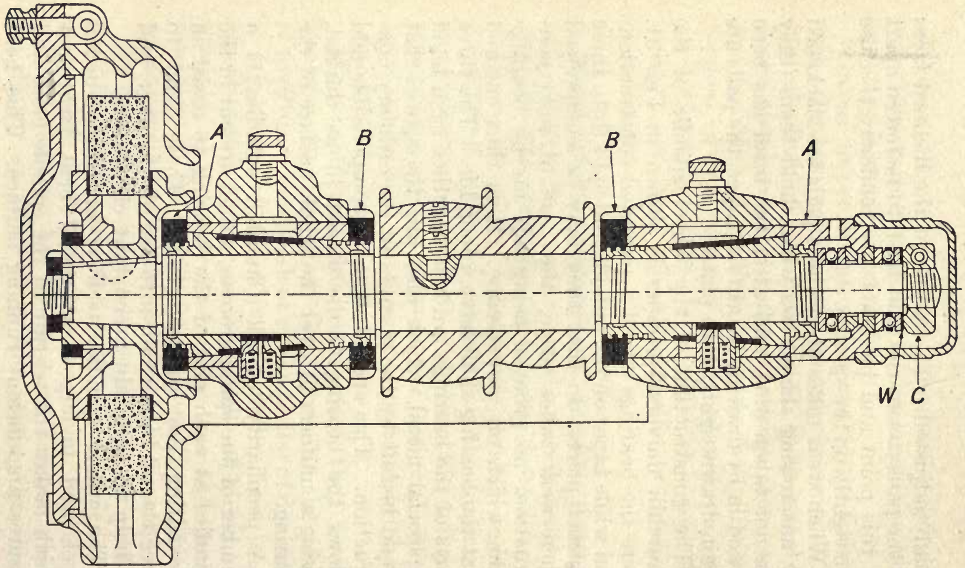


FIG. 31.—WHEEL HEAD OF CHURCHILL UNIVERSAL GRINDER

The patent "solid adjustable" bearings are adjusted by slackening nuts *AA* and tightening nuts *BB*. The spindle should float freely after adjustment. The nut *C* should be tightened only sufficiently to flatten the spring washer *W*.

treatment is used, not so much to give greater strength as to secure a bearing surface that will stand abuse if lubrication is neglected ; in this respect it is much to be preferred to a case-hardened spindle, which will develop cracks and quickly spoil the bearing surface if lubrication be neglected.

The end thrust has been so designed as to be taken by ball thrust bearings at one end of the spindle, so that the spindle is free to expand ; the bearings are therefore unaffected by varying temperatures of the spindle.

The Brown & Sharpe wheel-head (Fig. 32) has taper bearings for adjustment purposes, and these are carried in boxes with special seatings, so that the two bearings may be self-aligning. The boxes are held in position by hinged caps F, and may be removed easily for adjustment purposes. The adjustment of the bearings to the spindle is made by the lock nuts *C* and *D* at the ends of the bearings. Adjustment for end thrust is made by the part *A*, which is screwed on the end of the spindle and held in place by the lock screw *B*. Friction washers are placed between a collar on the spindle at the rear bearing and a shoulder on part *A*, which becomes virtually a part of the spindle. The driving pulley is held in place on a taper part of the spindle by means of the nut *J*.

Vertical Spindle Construction. The wheel head and spindle of the Blanchard grinder shown in Fig. 33 will well repay consideration. This is a design which is adapted admirably to meet the special requirements of a vertical spindle. The spindle is made from a forging of 0·4 to 0·5 per cent. carbon steel. It is finished all over by grinding,

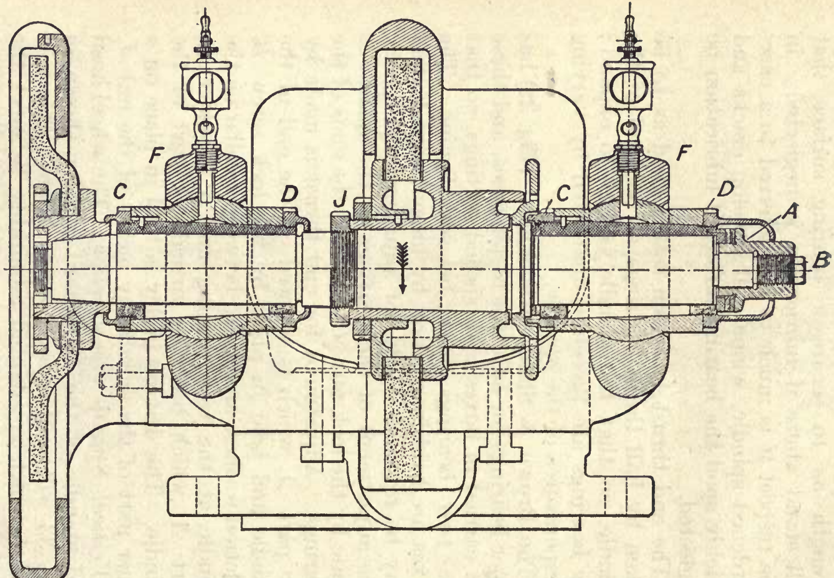


Fig. 32.—Wheel Spindle and Bearings of Brown and Sharpe Universal Grinder

and the main taper journal is lapped to an exact fit in its bronze bushing.

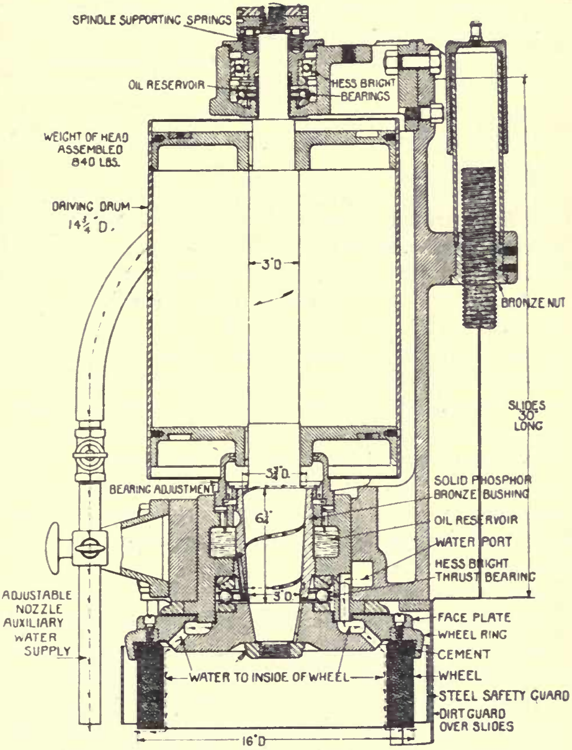


Fig. 33.—Wheel Head of Blanchard Vertical-Spindle Surface Grinder

As will be seen in the sectional view, the spindle is of very generous proportions throughout. The

faceplate or collet, to which the wheel plate is attached, is keyed on a taper and secured by a heavy nut. The drum for the driving belt is made a press fit on the spindle and is secured by a key in each hub. After assembling the drum on the spindle it is put in a special running-balance machine and carefully adjusted, by means of movable weights in the heads, to obtain perfect running-balance.

The bearings of the spindle comprise two ball-thrust bearings, together with a taper bronze bearing and one ball journal bearing. All are mounted in the sliding wheel head, making their alignment, relative to each other, independent of the slide. At the lower end, mounted directly on the face plate, is a large ball-thrust bearing. Above this is the taper bearing with solid phosphor-bronze bushing. This taper bearing is placed large end up, so that it is impossible to transfer to it any of the wheel thrust by improper adjustment. This bushing can easily be raised, by means of a threaded ring, to compensate for wear ; it is not split and consequently does not change its form when adjusted.

The upper end of the spindle carries a threaded collar, with springs beneath, which press up against it with a force exceeding the weight of the revolving parts by at least 200 lb. By this means, the thrust bearing at the lower end, on which depends the accuracy of the grinding, is always kept tight. All backlash in the spindle is eliminated and variations of spindle with temperature are automatically corrected.

The downward reaction of the springs is carried on a ball thrust bearing in the upper box, and side

pull at that point, due to the belt, is taken on a ball journal bearing.

Lubrication of the main thrust bearing is by a compression grease cup. The taper bronze bearing has automatic circulation of oil through it by means of the spirally grooved spindle. Its oil reservoir has a capacity of one quart and is adjacent to the cored passage conveying water to the wheel, so that the oil is cooled effectually. A gauge indicates the oil-level. The ball bearings in the upper bearing box run in an oil bath, with a gauge for indicating the oil-level. All the bearings are covered and protected against the entrance of grit or water.

Water Supply. The water supply is highly important in all grinding operations, inasmuch as cracked, burned and warped work results from excessive heating. This is particularly true in the case of surface grinding machines, such as the Blanchard machine, where the arc of contact is large and the production high. Under such circumstances water should be supplied in large volume at the point where the heat is being generated and should be applied in such a manner that the work and the abrasive grains which are doing the cutting may be cooled.

The Blanchard water system has been worked out on these lines. From the pump discharge pipe a 1 in. pipe runs to the wheel head, where it connects with the cored passage seen behind the main spindle in Fig. 33. The water passes down into the annular recess in the face and thence outward and downward inside the grinding wheel. As this water, in passing through the

inclined holes in the face-plate, is whirled at the full speed of the wheel, it issues from under the cutting face with considerable force and thoroughly cools and cleans the wheel face.

An auxiliary adjustable nozzle is provided to deliver a heavy stream directly over the work table. This supply is also through a 1 in. pipe. Both the inside and outside water pipes have independent valves.

Internal Spindles

There are two distinct types of internal spindles, the first or older design being known as the *tube type*, and having a bearing immediately behind the wheel. The disadvantage of this type lies in the fact that the tube with its bearing for the inner spindle is limited by the diameter of hole being ground, and therefore it is not to be recommended for holes less than, say, 6 in. in length ; holes of this length and longer are generally sufficiently large in the bore to admit a substantial spindle.

The other design of internal spindle is known as the *adapter type*, an example by the Churchill Co. being shown in Fig. 34. Its construction is such that the spindle bearings never enter the hole being ground, the wheel being carried on an adapter fitted into the main spindle and held by a draw-bolt. If the work to be ground is of limited range, the adapter portion may be formed integral with the main spindle, but for general commercial work the loose adapter type is preferable. Long or short, heavy or light adapters can then be used, suitable for the particular work in hand. At first sight this construction may appear to give less rigidity than the tube type, which has a bearing

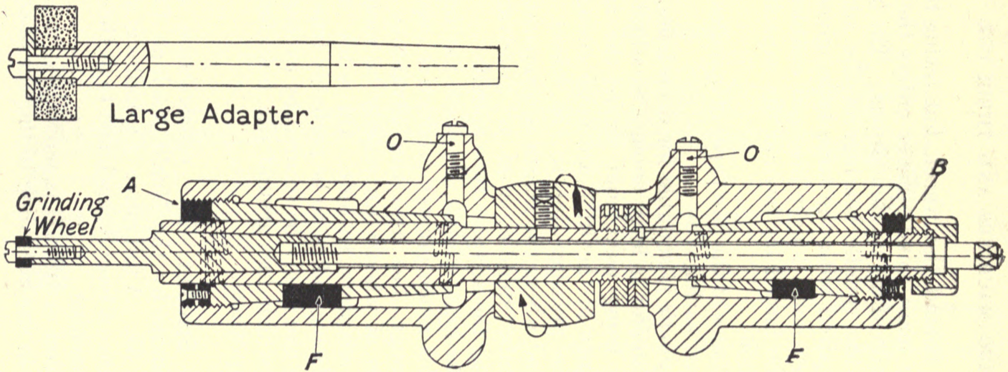


FIG. 34.—CHURCHILL ADAPTER-TYPE INTERNAL SPINDLE

A, B = Nuts which are tightened to adjust bearings for wear.
F = Felt pads.
O = Oil here.

immediately behind the wheel, but owing to the fact that the main spindle never enters the hole it may be made of liberal dimensions. The larger diameter of the spindle bearings of the adapter type as compared with the tube type, gives the spindle a very much longer life, and enables the grinding to be forced far beyond the capacity of the tube spindle.

The advantages of the two types of spindles may be summarized as follows—

The tube spindle is suitable for deep holes, and where the diameter is large enough to admit of a tube spindle being used, and where the actual spindle bearings in the tube are large enough to withstand the pressure due to the wheel. For small holes and where the length is comparatively short, the tube spindle is at a disadvantage compared with the adapter-type spindle.

The adapter-type spindle, besides having the advantage of a much greater productive capacity within its range, has also the advantage that different sizes of wheels can readily be mounted by making adapters to suit. On work which requires the face grinding to be perfectly true with the hole, this can easily be secured by exchanging the adapter which has ground the hole for one carrying a cup-wheel.

Tube-Type Spindles. The construction of a tube-type spindle by the Heald Machine Co. is shown in Fig. 35. A full range of spindles is made, all of which have a base *A* machined to fit the cross slide of the machine.

The extension or tube *B* is screwed in the base *A* and varies in size according to the size of hole to

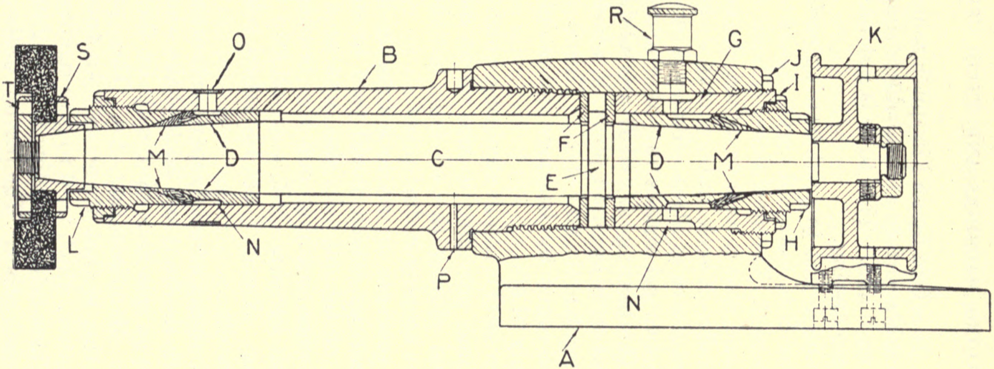


Fig. 35.—Heald Tube-Type Internal Spindle

be ground. It is held by an $\frac{1}{8}$ in.-pitch acme thread with the bearing surface and shoulders square and ground to no limits. This tube is not unscrewed from the base casting.

The spindle *C* has tapered bearing surfaces *D*, with a collar *E* to take end thrust against bronze thrust washers *F*. The steel sleeve *G* holds the rear bearing *H* and also is used to adjust the end play of the spindle. Check nuts *I* and *J* lock the bushing and sleeve in place. Pulley *K* drives the spindle by two set screws in order to maintain balance. The bearings *L* and *H* are solid. They are provided with birch oil plugs *M* which act as wicks and regulate the flow of oil. The oil reservoir *N* is cast all round the bearings and maintains an ample supply of oil.

The oil cover *O* is a split steel ring which springs over the tube, providing a convenient means of opening and closing the oil hole for the front bearing, yet keeping it dust-proof.

Hole *P* prevents an air lock forming between the two bearings, which would tend to stop free movement of the oil. It also acts as a drain, especially when washing out the bearings and spindle with kerosene. *R* is an oil cup for the rear bearing. *S* and *T* are the wheel collet and nut respectively.

When mounting wheels, paper washers should be used on both the front and back of the wheel.

A tube type spindle is also made by the Brown & Sharpe Manufacturing Co. The principal feature of this is that there are two tubes, one inside the other, which tend to give rigidity to the spindle. These tubes are adjustable longitudinally relative to each other. The portion of the spindle

carrying the pulley is mounted in two ball journal bearings which take the pull of the belt.

Fig. 36 shows the construction. *A*, is the base; *B*, the wheel spindle; *C*, the pulley spindle; and *D*, the pulley spindle ball bearings. The wheel spindle bronze box, *E*, is tapered on the outside to fit in the tapered hole of the outer shell, *F*, and this shell is made to screw on to the inner shell, G. It follows, that when the outer shell is turned upon the inner shell, the bronze box *E* is moved towards or from the inner shell, decreasing or increasing the end play of the wheel spindle collar *H*.

When the outer shell has been screwed on to the inner shell far enough to take up all end play of the collar *H*, further rotation of *F* forces the box *E* into the taper end of the outer shell and closes the box to compensate for wear. After the box has been forced far enough into the taper hole, the outer shell is unscrewed sufficiently to relieve the pressure on the collar *H*, and make a running fit. The wheel spindle, with its connecting shells, can be removed from the base without disturbing the pulley spindle, as connection is made by a clutch.

Another Churchill spindle is shown in detail in Fig. 37. This is one of the spindles in use on the internal cylinder grinding machine (*see* Fig. 12); it is of the tube type and is so constructed as to be very easily detachable from the main spindle. A full range of spindles of this type is made so that the smallest holes may be ground, and up to the maximum capacity of the machine; the best spindle can, therefore, be selected for the particular work in view.

It will be seen that the front bearing is a parallel bearing with taper bush for adjustment, which

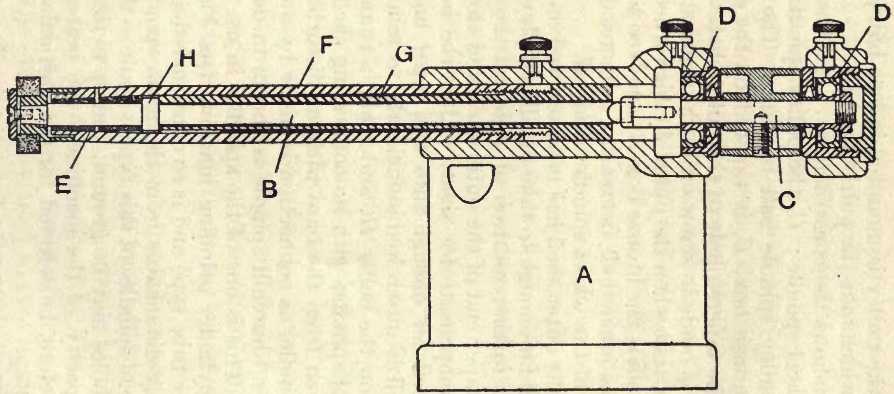


Fig. 36.—Brown & Sharpe Internal Spindle

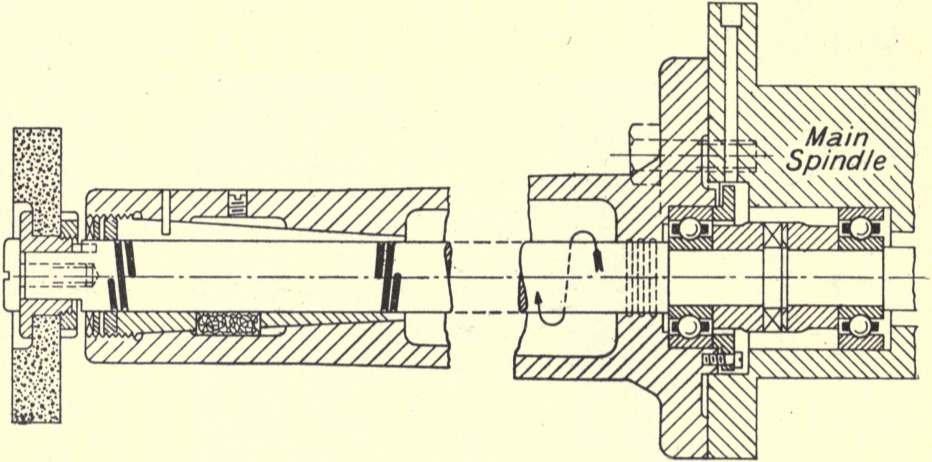


FIG. 37.—DETACHABLE SPINDLE FOR CHURCHILL PLANETARY TYPE INTERNAL GRINDER

gives a close and steady running fit to the spindle, so that there is no vibration or tremor at the extreme end of the spindle. At the flanged end of the spindle there is a ball bearing. Connection between the wheel spindle and the driving spindle inside the planetary spindle is made by means of a clutch, the mating half of which is fixed on the spindle.

Automatic Cross-Feed. The automatic cross-feeding mechanism of a grinding machine provides a positive means of drawing-in the wheel head and of stopping the feed when the diameter of the work has been reduced to a pre-determined size. In all grinding machines of the sliding table type it is common to use a ratchet wheel fastened to a shaft that controls the traverse movement of the head. A pawl actuated through levers from the reversing dogs on the sliding table operates the ratchet wheel and automatically draws the wheel head in at each reversal of the table. The pawl continues to feed the ratchet wheel until a shield, or trip plate, that is concentric and revolves with the ratchet wheel, lifts it out of engagement and prevents it from further engaging the ratchet teeth. The cross-feed is automatically thrown out of action when this point is reached.

The Churchill micrometer feed disc (Fig. 38) is a particularly neat piece of work. The trip plate is a steel disc, and the mechanism for adjusting its position is entirely enclosed and protected from water and grit. It may be quickly set by turning the handle or knob, which, with a little crank attached to it, is seen in front of the micrometer plate. Inside the plate the knob is attached to a small

pinion in mesh with an internal gear, which is part of the trip plate. The holes in the small index plate are spaced so that each space corresponds

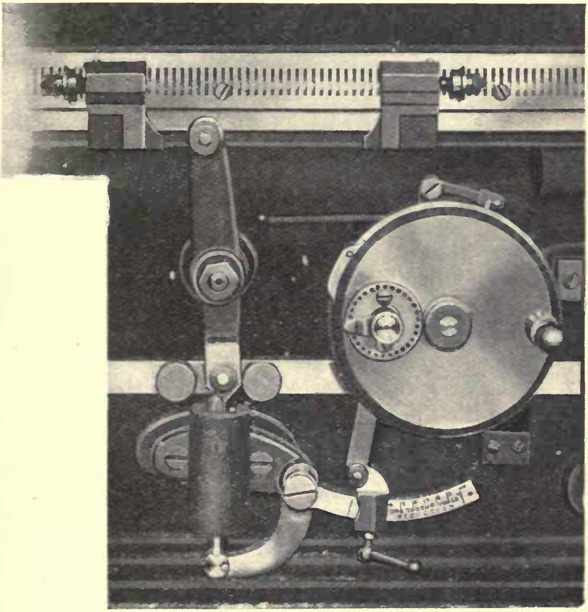


FIG. 38.—CHURCHILL MICROMETER FEED DISC

to one tooth of the ratchet wheel and represents 0·00025 in. in diameter on the work.

A question often asked by those unfamiliar with grinding is: "How can a large number of similar pieces of work be made a uniform diameter when the grinding wheel is wearing all the time?"

As in all machining operations, it is, of course, necessary that the operator should constantly gauge the work to see that there is no variation and, when such is found to occur, all that is necessary is to turn the little handle on the front of the micrometer plate, Fig. 38. One space moved by the locating plunger on this moves the trip plate back a distance corresponding to 0·00025 in. in diameter; it is thus possible to compensate easily and accurately for the variation from size.

The cross-feed on all grinding machines must of necessity be very fine on account of the work it it called upon to do. It frequently happens, however, that there are considerable variations of diameter in pieces which require to be finished by grinding, and, if the feed alone be available, it is a great time loser when it is necessary to transfer the wheel from a larger to a smaller diameter of work, or *vice versa*. To obviate this loss of time, a quick hand motion is fitted to the medium sized machines (*see* Fig. 39), and a quick power motion to the larger sizes. This additional device does not in any way interfere with the ordinary fine feed and trip motion ; in the Churchill arrangement it consists of an auxiliary shaft and a hand wheel, with the necessary gearing to give a high ratio between the two speeds. The slow motion may be disengaged when the quick motion is in use and a one-tooth clutch ensures re-engagement in the same relative positions.

An illustration of the Brown & Sharpe mechanism is given in Fig. 40. The action of this is as follows: The ratchet wheel is graduated and each tooth is equal to a movement of the wheel slide of $\frac{1}{8000}$ in. (0·000125 in.) or a reduction of $\frac{1}{4000}$ in. (0·00025 in.)

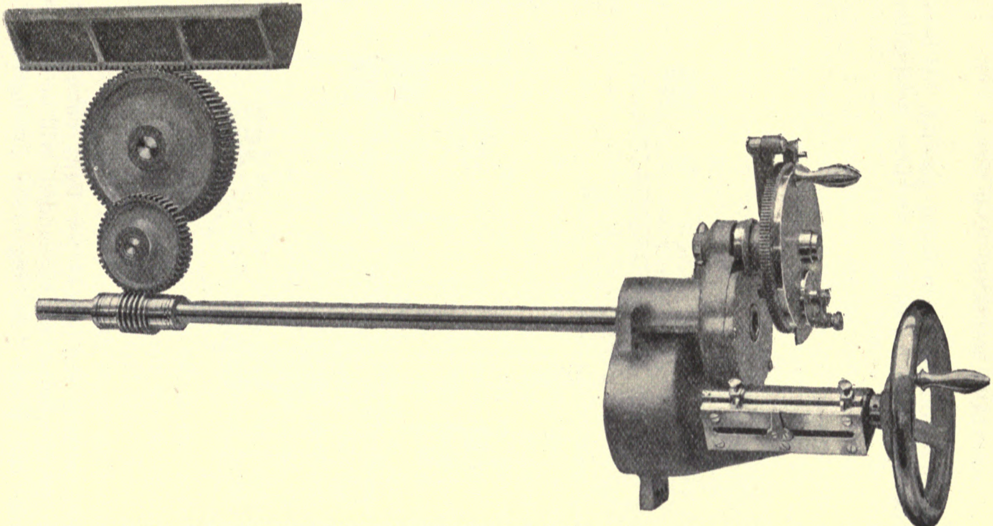


Fig. 39.—Wheel Feed Mechanism of Churchill Plain Grinder

in diameter on the piece being ground. It is not necessary, however, to look at these graduations

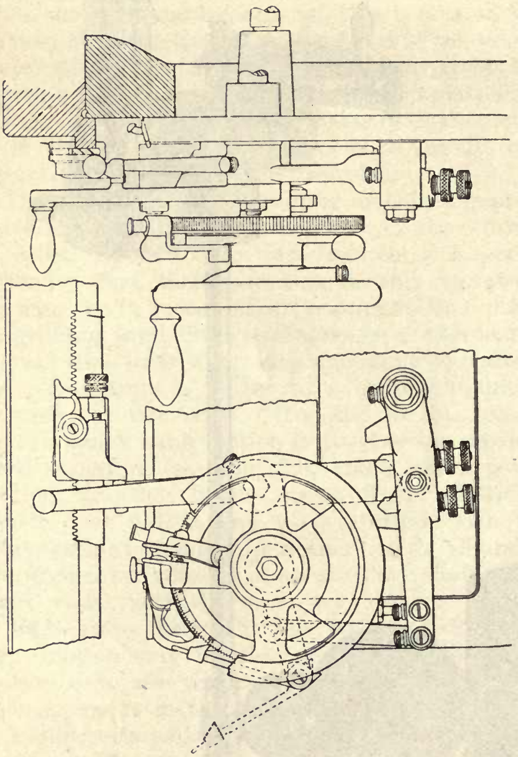


FIG. 40.—BROWN & SHARPE AUTOMATIC CROSS-FEED

when setting the shield for light cuts, so that any given number of thousandths will be removed from the piece. An ingenious arrangement is

provided for this purpose, consisting of a latch-like mechanism that is pinched between the thumb and fore-finger ; each time this is done the shield moves back one tooth on the ratchet wheel. So, if it is required to remove a given amount, the grinding wheel is drawn in by means of the hand wheel until it just trues up a place on the work. The diameter is measured carefully at this point and then, if there are two-thousandths more to come off, the latch is pinched four times for each thousandth to be removed, or eight times for the two-thousandths. The machine will then grind exactly two thousandths from the piece and, if this is the correct size required, succeeding pieces can be ground to the same diameter without disturbing the adjustment of the mechanism. Before a new piece of work is put in, the wheel slide is moved back by simply throwing the pawl out of engagement and turning the hand wheel. It is then moved up until the wheel just touches the work, the pawl is thrown into action, and the table traverse started. When the pawl reaches the shield the cross feed will be thrown out and the piece will be the same diameter as the previous one. As the wheel wears, a slight adjustment of the slide can be made, by means of the latch, to maintain constant diameter of finished work.

Reversing Mechanisms. To effect the reversal of the moving slide two methods are in common use, viz., the V–point reverse and the " load and fire " mechanism. The *V–point reverse* mechanism, which is the simpler and more commonly used, operates as follows: When the dog catches the reversing lever, this is moved without moving the

clutch, but immediately it has passed an upright position it is thrown very quickly over to the other

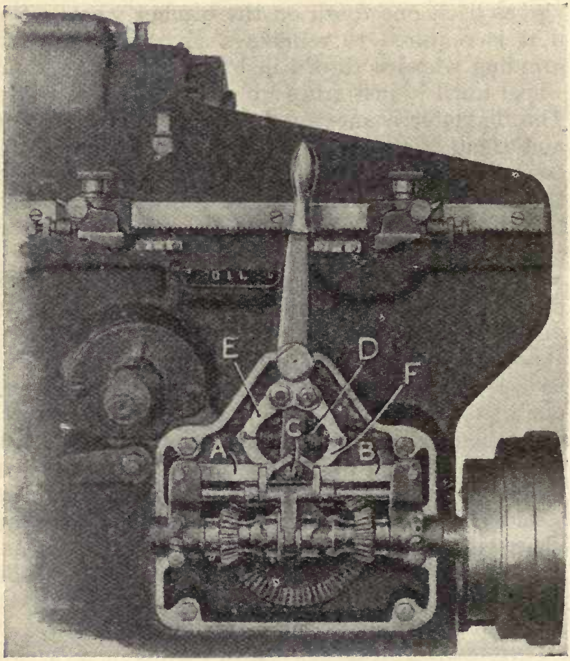


FIG. 41.—"LOAD AND FIRE" REVERSE MECHANISM
(Persons-Arter Rotary Surface Grinder)

side by the action of a strong spring and a plunger, with inclined faces carried in a bracket below it. The lever coming into contact with projections on the reversing rod gives an endwise movement to

this, which is transmitted to a reversing box. This is a box enclosing the reversing gears, consisting of a bevel gear and two pinions, with a clutch sliding between the pinions and controlled by the reversing rod. The clutches are of the saw-tooth form, so that they will engage at once, even if two teeth come together. From the reversing box the motion is transmitted to the slide by gearing and finally by rack and pinion. The reversing lever is usually fitted with a spring plunger, which can be drawn back when it is desired to examine the condition of the work or wheel, allowing the slide to run past the reversing points without disturbing the adjustment of the dogs. The plunger automatically assumes its normal position when the slide is returned.

The *load and fire reverse* is made in several forms, one of which is illustrated by Fig. 41. When the reversing lever is thrown to one extreme by contact with one of the stop dogs, or by hand, one of the two latches *A* or *B* is raised, and the sliding clutch engages one of the bevel pinions. As the slide travels, the other dog throws the lever over, causing pin *C* to raise the other latch ; the clutch then moves over, under the action of the spring *D*, and engages with the opposite pinion. In the position shown in Fig. 41, latch *B* is in contact with the clutch fork and holds this securely until the latch is lifted by the pin *C*. Only one spring *D* is used, and this is secured between two curved arms, *E* and *F*, loosely pivoted on the reversing lever, the ends abutting against the clutch fork. As the reverse lever moves, the free arm moves with it, thereby putting tension on the spring until the latch is lifted.

CHAPTER V

CARE AND OPERATION OF GRINDING WHEELS AND MACHINES

Grinding Limits and Allowances. In considering a piece of work to be ground, first of all the question arises as to the size and the limits suitable for the purpose for which it is intended. Table II gives the limits used at the Brown & Sharpe Manufacturing Co.'s works for varying conditions. There are special cases in which it may be necessary to increase or to decrease these limits, and this table is not offered as the final word, but as a guide towards selection.

TABLE II

GRINDING LIMITS FOR CYLINDRICAL PIECES*

(As adopted by Brown & Sharpe Mfg. Co.)

Class of Fit	Diameter of Work		Grinding Limits	
	Over	Up to Inclusive		
	In	In	In	
RUNNING FITS—Ordinary Speed	—	½	0·00025–0·00075	SMALL
	½	1	0·00075–0·0015	
	1	2	0·0015 –0·0025	
	2	3½	0·0025 –0·0035	
	3½	6	0·0035 –0·005	
RUNNING FITS—High Speed, Heavy Pressure and Rocker Shafts	—	½	0·0005 –0·001	SMALL
	½	1	0·001 –0·002	
	1	2	0·002 –0·003	
	2	3½	0·003 –0·0045	
	3½	6	0·0045 –0·0065	

* The limits given in the table can be recommended for use in the manufacture of machine parts to produce satisfactory commercial work. These limits should be followed under ordinary conditions. Special cases should always be considered, as it may be desirable to vary slightly from the tables.

TABLE II—(*contd.*)

Class of Fit	Diameter of Work: Over	Diameter of Work: Up to Inclusive	Grinding Limits	
SLIDING FITS	—	½	0·00025–0·0005	SMALL
	½	1	0·0005 –0·001	
	1	2	0·001 –0·002	
	2	3½	0·002 –0·0035	
	3½	6	0·003 –0·005	
STANDARD FITS	—	½	Standard–0·00025	SMALL
	½	1	Standard–0·0005	
	1	2	Standard–0·001	
	2	3½	Standard–0·0015	
	3½	6	Standard–0·002	
DRIVING FITS— For such Pieces as are Required to be Readily Taken Apart	—	½	Standard–0·00025	LARGE
	½	1	0·00025–0·0005	
	1	2	0·0005 –0·00075	
	2	3½	0·00075–0·001	
	3½	6	0·001 –0·0015	
DRIVING FITS	—	½	0·0005 –0·001	LARGE
	½	1	0·001 –0·002	
	1	2	0·002 –0·003	
	2	3½	0·003 –0·004	
	3½	6	0·004 –0·005	
FORCING FITS	—	½	0·00075–0·0015	LARGE
	½	1	0·0015 –0·0025	
	1	2	0·0025 –0·004	
	2	3½	0·004 –0·006	
	3½	6	0·006 –0·009	
SHRINKING FITS— For Pieces to take hardened Shells ⅜ in. Thick and Less	—	½	0·00025–0·0005	LARGE
	½	1	0·0005 –0·001	
	1	2	0·001 –0·0015	
	2	3½	0·0015 –0·002	
	3½	6	0·002 –0·003	
SHRINKING FITS— For Pieces to take Shells, etc., having a Thickness of more than ⅜ in.	—	½	0·0005 –0·001	LARGE
	½	1	0·001 –0·0025	
	1	2	0·0025 –0·0035	
	2	3½	0·0035 –0·005	
	3½	6	0·005 –0·007	
GRINDING LIMITS FOR HOLES	—	½	Standard–0·0005	LARGE
	½	1	Standard–0·00075	
	1	2	Standard–0·001	
	2	3½	Standard–0·0015	
	3½	6	Standard–0·002	
	6	12	Standard–0·0025	

The second necessity is that sizes should be established to which the work should be rough turned ready for grinding. To do this work as cheaply as possible the Brown & Sharpe Co. turn the pieces to about the sizes indicated in Table III. It will be noted that they allow from 0·008 in. to 0·012 in. in diameter, and in order to make this work as easy as possible for the lathe department, they provide limit gauges with "go" and "not go" ends, to the respective dimensions given in the table.

TABLE III

LIMIT GAUGES FOR LATHE WORK

(All dimensions in inches)

Size	Not Go On	Go On	Size	Not Go On	Go On	Size	Not Go On	Go On
$\frac{3}{8}$	0·383	0·387	$\frac{15}{16}$	0·9455	0·9495	$1\frac{1}{2}$	1·508	1·512
$\frac{7}{16}$	0·4455	0·4495	1	1·008	1·012	$1\frac{9}{16}$	1·5705	1·5745
$\frac{1}{2}$	0·508	0·512	$1\frac{1}{16}$	1·0705	1·0745	$1\frac{5}{8}$	1·633	1·637
$\frac{9}{16}$	0·5705	0·5745	$1\frac{1}{8}$	1·133	1·137	$1\frac{11}{16}$	1·6955	1·6995
$\frac{5}{8}$	0·633	0·637	$1\frac{3}{16}$	1·1955	1·1995	$1\frac{3}{4}$	1·758	1·762
$\frac{11}{16}$	0·6955	0·6995	$1\frac{1}{4}$	1·258	1·262	$1\frac{13}{16}$	1·8205	1·8245
$\frac{3}{4}$	0·758	0·762	$1\frac{5}{16}$	1·3205	1·3245	$1\frac{7}{8}$	1·883	1·887
$\frac{13}{16}$	0·8205	0·8245	$1\frac{3}{8}$	1·383	1·387	$1\frac{15}{16}$	1·9455	1·9495
$\frac{7}{8}$	0·883	0.887	$1\frac{7}{16}$	1·4455	1·4495	2	2·008	2·012

Wheel Mounting. As one particular grit and grade of grinding wheel is not suitable for all work which may be required, the wheel may have to be changed frequently. If this is the case the wheels should be kept mounted on holders or collets, and the complete wheel and collet should be changed, and not the wheel only.

Examples of collets have already been illustrated in Figs. 31–33, and another type is shown in Fig. 42. On all the smaller machines the collet fits

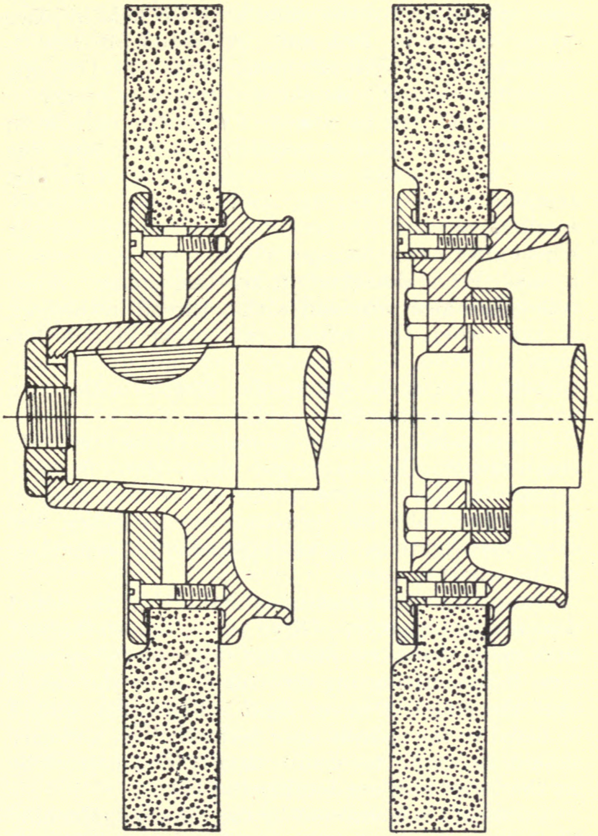


Fig. 42.—Taper and Flanged Spindle Noses

the tapered end of the spindle, and is held in place by a left-hand lock-nut. A Woodruff key is employed to prevent all chance of the wheel coming loose if the spindle should be stopped suddenly.

The collet can be removed from the spindle in far less time than is required to unmount the wheel alone. This saves considerable time and trouble when changing, and is also decidedly economical, as it obviates the need for truing the wheel after every change, which is necessary when it has been detached from the collet. Some collets are also provided with a thread in the end, so that when the locking nut on the spindle has been removed, an extractor may be screwed into this thread, and the whole collet thereby withdrawn without damaging the spindle.

Compressible washers of pulp, rubber, or cork composition, slightly larger than the flanges, should be used between the wheel and flanges. They distribute the pressure evenly when the flanges are tightened by taking up any imperfections in the wheel or flange.

Complaints are sometimes made that the collet does not fit properly. Often this is due to the fact that operators have oiled the taper of the spindle nose before fitting on the collet, with the result that the collet is never rigid. The collet should be fitted to the spindle nose perfectly dry, and care should be taken to ensure that it is a correct fit on the taper and not fouling the key.

A problem encountered by the Churchill Machine Tool Co. was that of mounting large diameter grinding wheels, ranging from 30 in. to 60 in. diameter, in such a way that they would be held rigidly in the plane in which they had to rotate.

Their experience of the then exclusively used taper-end mounting was not altogether satisfactory, owing to the extreme difficulty of making a perfect fit on short abrupt tapers, and also to the fact that operators would persist in oiling or greasing the taper of the spindle nose before fitting on the collet, which in itself defeated the object in view. The problem was solved by designing a flanged spindle nose for use with all wheels above 30 in. diameter ; the wheel collet is centred on a projecting spigot and securely bolted up to the flange of the spindle. Fig. 42 shows the two methods of mounting.

Wheel Balance. It is probably true that a large proportion of the trouble experienced in precision grinding can be traced to an out-of-balance condition of the wheel. Due to the fact that wheels are apt to vary very slightly in density, it is difficult to make a wheel that will be in perfect balance and, although a grinding wheel may be in balance when it is new, it does not follow that it will always remain in balance. As the wheel wears down, dense or light spots may be removed, thus destroying the balanced condition. Because of this fact it is necessary occasionally to try wheels for balance and to correct any out-of-balance condition that may exist.

Probably nine-tenths of all spindle trouble with cylindrical grinding machines is caused by efforts on the part of the operator to obtain good work by so tightening the bearings as to prevent an out-of-balance wheel from causing marks in the work. No matter what effort may be made on the part of the machine maker to produce spindles and

bearings of the best design and construction, they can be ruined and are ruined by operators attempting to tighten the bearing sufficiently to prevent out-of-balance forces in the wheel from causing marks in the work. It is impossible to prevent out-of-balance forces from causing marks on the work, but many spindles and bearings are ruined in the vain attempt.

Never tamper with a wheel spindle bearing unless you are thoroughly conversant with its construction.

In order to maintain a good running balance the wheel collets are sometimes fitted with movable balance weights, the position of which can be adjusted as required to maintain the balance.

Prevention of Distortion. One of the evils to be guarded against in grinding is local heating of the work and consequent distortion and inaccuracy. Low work-speed is directly conducive to such conditions, and is therefore to be avoided. The heat created by the cutting action of the wheel must be dissipated or distributed as quickly as possible, and this can only be done by high work-speed and rapid table travel, aided by an ample flow of water. A very good illustration of this is the grinding of hollow work, where there is no body of metal to absorb and distribute the heat. Such work can only be ground successfully by a combination of high table-speed and work-speed, so that the whole area of the ground surface may be covered as quickly as possible. A good example of such work, although small, is the external grinding of rifle barrels.

There is a popular notion that water and lubricants of various kinds are used to keep work cool.

It is not at all necessary that the work should be kept cool when grinding, but it is necessary that the heat be dissipated quickly, so that the work is kept at a nearly *uniform temperature* during the passage of the wheel over the entire length being ground. It is not necessary that it should be maintained at any particular temperature. It may be cold or it may be hot, and it is not necessary that the work be of the same temperature for different passes over the same piece of work. In order that the work may remain straight, it is only necessary that during each pass the temperature shall remain nearly constant from one end of the pass to the other.

Increasing temperature from the end to the centre will cause the work to "spring," so that the wheel cuts deeper on one side of the work than on the other side; when the work returns, the wheel will cut on the opposite side. During the next pass it will cut deeper at right angles, and so on, as long as grinding continues with insufficient lubricant or with a wheel too hard for the work, or both.

It is therefore essential that the supply of lubricant be ample in volume, but without force. Ample supply never yet limited production or spoiled any work. The best lubricant is one of the soluble oils, of which there are many good samples on the market, mixed in the proportion of 1 part of oil to 30 parts of water.

For grinding bronze or copper, paraffin oil will be found beneficial, and for aluminium, a mixture of oil and paraffin in equal parts.

Centres in Work. It is important that these holes should be made as accurately as the centre

itself in the machine. Too much importance cannot be placed upon the refinement in the centre holes for ground work. The angle of the hole should agree exactly with the angle of the centre that the work is to rest on. The shape of the hole should be as perfect as it is practical to make it, for no work can be ground more perfectly than the holes fit the centres which the work revolves on while grinding. If they are incorrectly balanced, out of shape or poorly made, the quality of work will correspond with the inaccuracies in the centre holes. The surfaces that rest on the centre points should be as smooth and as free from chatters and imperfections as they can be made. Slight chatters in the centre holes will be reflected in the ground surface. The hole should be deep and the drill relief at the bottom should extend far enough to give ample clearance for the centre point, so that this will not bottom in the hole while grinding.

Loosely fitting centres that are liable to move, badly made centre holes, or centres that are not kept true, are frequently the cause of eccentric grinding at the extremities of the work. In some cases this trouble may be traced to softness of the machine centres which allows them to wear rough and abrade the centre holes in the work.

Table Travel in Relation to Wheel Width. It will readily be realized that it is of very little use to have a wide wheel in combination with a slow table traverse. The only result of such a procedure would be a limitation of the production of the machine, and excessive wear on the portion of wheel used, causing the wheel to generate a round

face, and making frequent truings necessary in order to cut away the unused portion of the wheel.

It is a question often raised as to whether the wheel keeps flat when grinding work with shoulders, as, of course, it will be seen that if a wheel wears round on its cutting face, the portion of a shaft nearest to the shoulder will be of somewhat larger diameter. It can be laid down as a definite rule that " if the traverse of the work per revolution is less than half the width of the wheel, then the cutting face of the latter will gradually wear convex, but if the traverse per revolution of the work is over half the width of the wheel, then the wheel will preserve a flat face."

The *ideal traverse per revolution of the work* is about two-thirds the width of the wheel, and it should not, except for finishing, be less than half the width of the wheel. The speed of table travel is thus seen to be of very great importance if maximum production is to be assured, and it is due to the realization of this fact that the Churchill Co. build grinding machines with table speeds of 16 ft. per min. and over, in combination with wide grinding wheels.

Work-Speeds. Suitable work-speeds are as follows—

Cylindrical Grinding:

External . . .	60 ft. per min.
Internal . . .	120 ft. per min.

Surface Grinding:

Vertical spindle .	15 ft. per min.
Rotary table .	80 ft. per min.

Table IV will be found convenient when considering the question of the most suitable diameter of wheel as governed by the spindle speeds available on the grinding machine concerned.

TABLE IV

GRINDING WHEEL SPEEDS

Diameter of Wheel in Inches	Revs. per Min. for Surface Speed, in Feet per Min.						
	4,000	4,500	5,000	5,500	6,000	6.500	7,000
1 . .	15,279	17,189	19,099	21,009	22,918	24,829	26,738
2 . .	7,639	8,594	9,549	10,504	11,459	12,414	13,369
3 . .	5,093	5,729	6,366	7,003	7,639	8,276	8,913
4 . .	3,820	4,297	4,775	5,252	5,730	6,207	6,684
5 . .	3,056	3,438	3,820	4,202	4,584	4,966	5,346
6 . .	2,546	2,865	3,183	3,501	3,820	4,138	4,456
7 . .	2,183	2,455	2,728	3,001	3,274	3,547	3,820
8 . .	1,910	2,148	2,387	2 626	2,865	3,103	3,342
10 . .	1,528	1,719	1,910	2,101	2,292	2,483	2,674
12 . .	1,273	1,432	1,592	1,751	1,910	2,069	2,228
14 . .	1,091	1,228	1,364	1,500	1,637	1,773	1,910
16 . .	955	1,074	1,194	1,313	1,432	1,551	1,611
18 . .	849	955	1,061	1,167	1,273	1,379	1,485
20 . .	764	859	955	1,050	1,146	1,241	1,337
22 . .	694	781	868	955	1,042	1,129	1,215
24 . .	637	716	796	875	955	1,034	1,114
26 . .	586	661	733	806	879	955	1,022
28 . .	546	614	683	750	819	886	955
30 . .	509	573	637	701	764	827	871
32 . .	477	537	596	651	716	776	836
34 . .	449	506	561	618	674	730	786
36 . .	424	477	531	584	637	689	743
40 . .	382	430	478	526	573	621	668
42 . .	364	409	455	500	546	592	637
44 . .	347	390	434	478	521	564	608
48 . .	318	358	397	437	477	517	557
50 . .	306	344	383	421	459	496	535

Wear of Grinding Wheels.* The wear of a grinding wheel when used for the various operations of external, internal and surface grinding

* H. H. Asbridge, The Churchill Machine Tool Co., Ltd.

on the respective machines would appear to have a constant relationship to the amount of metal removed, so that a large diameter grinding wheel used for cylindrical grinding lasts longer than a smaller wheel, simply because it is of larger diameter, and has a greater number of cubic inches which can be used during its effective life.

Given correctly graded wheels, employed under similar conditions, it has been proved that wheel wear on external cylindrical grinding is practically proportional to wheel diameter. Comparing wheels of the same width and, say, 12 in. and 24 in. diameter, the larger wheel will remove rather more than double the amount of metal per cubic inch of wheel wear. As the cost of wheels is almost a constant per effective cubic inch, it naturally follows that the larger wheel is the more economical proposition.

In order to make this statement of more value and to give a basis for comparison purposes, the following data were obtained on machines employed on similar work, rough and finish grinding, mixed classes of steel, both hardened and in a soft state. A wheel 14 in. diameter by 2 in. wide removed an average of 8 cu. in. of metal per 1 cu. in. of wheel wear, whereas a wheel 24 in. diameter by 2 in. wide removed an average of 19 cu. in. of metal per 1 cu. in. of wheel wear. The metal removed per cubic inch of wheel wear was thus 2·37 times greater in the case of the larger wheel. Taking the cost of each wheel to be 3d. per effective cubic inch of wheel, the cost per cubic inch of metal removed by the 14 in. by 2 in. wheel is 0·375d. compared with 0·16d. for the 24 in. by 2 in. wheel.

It will be seen, therefore, that although large wheels do not directly affect output, they are decidedly more economical in use. Large wheels require the use of heavier and more rigid machines, which cost more in the first place but are a better investment because, other things being equal, the large-wheel machine is the more powerful tool and consequently the higher producer.

The above figures must not be regarded in any way as a maximum, but only as a guide for wheels employed on a general run of work. When employed on repetition finishing work, under constant conditions, the life of good wheels is easily 50 per cent. greater.

Quick-Acting Driver. Fig. 43* shows a quick-acting driver which may be placed quickly on the work and automatically provides the proper grip for driving the piece to be ground. The pin which engages the driver on the face plate is made in the form of a cam, the pivot being placed off centre to make it eccentric. The position of this pivot with relation to the centre is decided by the direction of rotation of the face plate, because, when the driving pin on the face plate engages this cam, it must tend to tighten it on the work for driving. The amount of camming effect must be decided upon by trial in order to provide the proper pinch, so that the work will not slip.

In order that work may be removed more quickly, a flat spring is sometimes used to cause the cam pin to open directly it is disengaged from the driving pin on the face plate. This is not always

* Reproduced from *Grits & Grinds* by permission of the Norton Co., U.S.A.

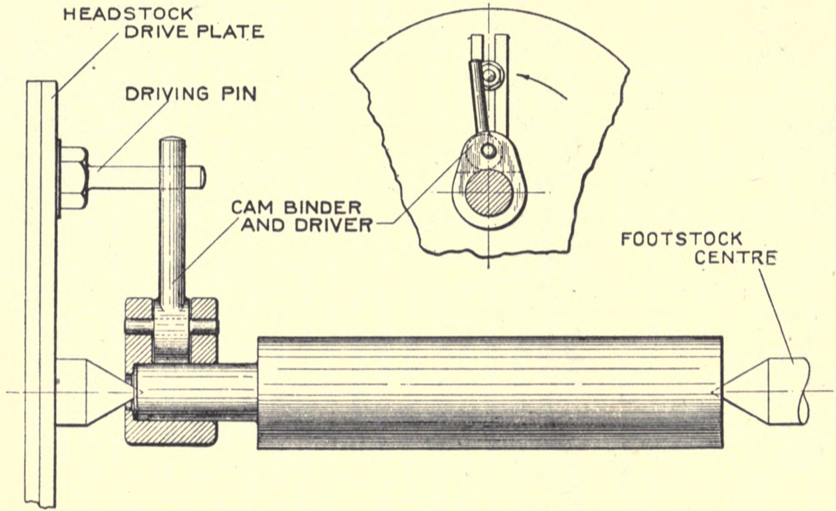


Fig. 43.—Quick-Acting Driver

done but it offers a modification and a slight improvement in some cases.

The hole which receives the end of the work to be driven is slightly larger than the diameter of the work, so that the driver will always go on easily, and the hole in the driver is a bottomed hole, so that the driver always comes to the same point and trouble is not experienced from the work sliding through the hole.

Expanding Arbor. Another interesting fixture from the same source is shown in Fig. 44. This is particularly suitable for holding thin shells, because the expanding arbor obtains a three-point bearing at either end of the shell or cylinder, and is of such proportions that it distorts the work being ground less than any other holding device.

Such an arrangement must of necessity be used with a live spindle attachment, the work being slipped over the arbor and held in place by tightening up with a hand screw, on the back of the live head which draws the bolt carrying the expanding members into the split shell. The angle on the ends of these expanding members engages the ends of the split member and causes it to bind on the internal diameter of the piece being held.

This form of holder has been used successfully on shells as small as $1\frac{1}{2}$ in. diameter $\times$ $2\frac{1}{2}$ in. long, with a wall thickness of less than $\frac{1}{8}$ in., and has also been used successfully on motor cylinders.

Special Running Driver. It is sometimes desired to have a running driver for use with a dead centre head. Such an arrangement is shown

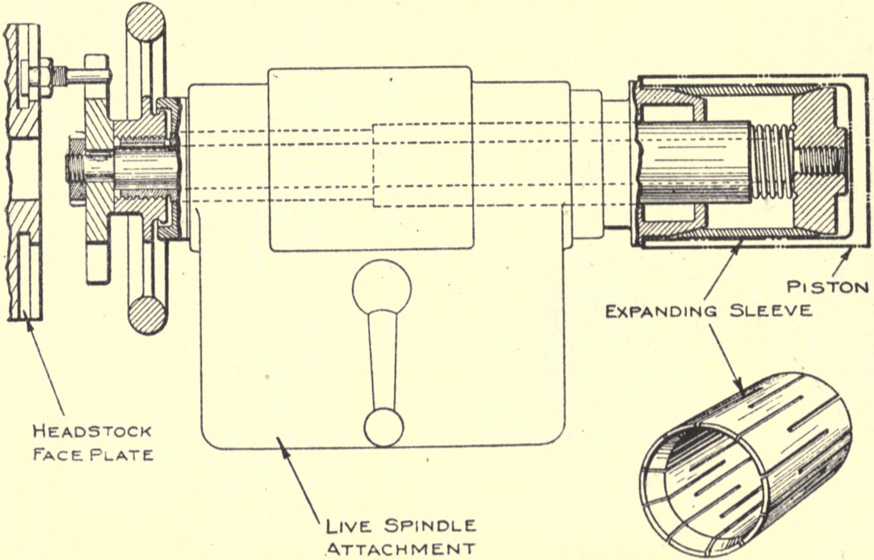


FIG. 44.—EXPANDING HOLDER ON LIVE SPINDLE

in Fig. 45. The body of the driver *A* runs on a dead centre *B*, the bearing portion being of the form known as the Schiele curve, which is capable

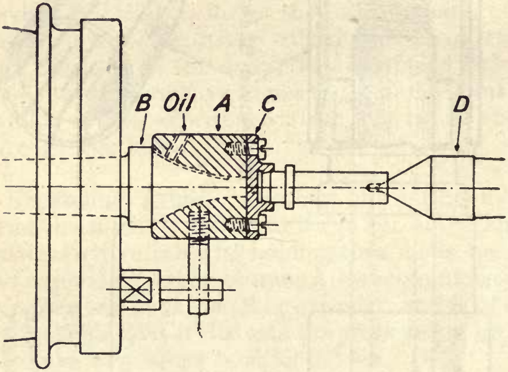


FIG. 45.—SPECIAL RUNNING DRIVER FOR PINS

of taking both bearing pressure and end thrust. The cap *C* is secured to the rotating piece *A* and has an internal cone, into which the work is pressed, by the tailstock centre *D*, with sufficient force to hold and drive it.

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